Summaries of the 58 chapters of Life, the Science of Biology 7th edition

CHAPTER 1: AN EVOLUTIONARY FRAMEWORK FOR BIOLOGY What Is Life? Life can be defined as an organized genetic unit capable of metabolism, reproduction, and evolution. Metabolism, the total chemical activity of a living organism, is controlled by genes. Biological evolution is a change in the genetic composition of a population of organisms over time. Biological Evolution: Changes over Billions of Years Charles Darwin's theory of natural selection rests on three simple observations and one conclusion drawn from them: Any heritable traits that increase the probability that their bearers will survive and reproduce are passed on to their offspring. Review Figure 1.2 Major Events in the History of Life on Earth Life arose from nonlife about 4 billion years ago by means of chemical evolution. Review Figure 1.3 Biological evolution began about 3.8 billion years ago when interacting systems of molecules became enclosed in membranes to form cells. Photosynthetic prokaryotes released large amounts of oxygen into Earth's atmosphere, making aerobic metabolism possible. Complex eukaryotic cells evolved by incorporation of smaller cells that survived being ingested. Multicellular organisms appeared when cells evolved the ability to transform themselves and to stick together and communicate after they divided. The individual cells of multicellular organisms became modified to carry out varied functions within the organism. The evolution of sex sped up rates of biological evolution. Levels of Organization of Life Life is organized hierarchically, from molecules to the biosphere. Review Figure 1.6. See Web/CD Activity 1.1 The Evolutionary Tree of Life A major effort called Assembling the Tree of Life (ATOL) is underway to determine the evolutionary relationships among all species on Earth. The hierarchy of evolutionary relationships can be represented as an evolutionary tree. Review Figure 1.8. See Web/CD Activity 1.2 Species are grouped into three domains: Archaea, Bacteria, and Eukarya. The domains Archaea and Bacteria consist of prokaryotic cells. The domain Eukarya contains the Protists, Plantae, Fungi, and Animalia. Biology Is a Science Biologists use a variety of technical and conceptual tools to study living things. The hypothesis-prediction (H-P) approach is used in most biological investigations. Hypotheses are tentative answers to questions. Predictions are made on the basis of a hypothesis. The predictions are tested by experiments and comparative observations. Review Figures 1.9 and 1.10 Science can tell us how the world works, but it does not form the basis for establishing meaning and values. Biologists are often called upon to advise governmental agencies on the solution of important problems that have a biological component. CHAPTER 2: LIFE AND CHEMISTRY: SMALL MOLECULES Water and the Origin of Life's Chemistry Current scientific evidence indicates that life as we know it cannot exist without water, and that life on Earth originated in the water of the planet's primordial oceans. The chemistry of life is ancient. Earth began forming about 4.6 billion years ago, and the first signs of life are 3.8-4 billion years old. Atoms: The Constituents of Matter Matter is composed of atoms. Each atom consists of a positively charged nucleus of protons and neutrons, surrounded by electrons bearing negative charges. There are many elements in nature, but only a few of them make up the bulk of

living systems. Review Figures 2.2, 2.3 Isotopes of an element differ in their numbers of neutrons. Some isotopes are radioactive, emitting radiation as they decay. Review Figure 2.4 Electrons are distributed in shells consisting of orbitals. Each orbital contains a maximum of two electrons. Review Figures 2.6, 2.7. See Web/CD Activity 2.1 In losing, gaining, or sharing electrons to become more stable, an atom can combine with other atoms to form molecules. Review Table 2.1 Chemical Bonds: Linking Atoms Together Covalent bonds are strong bonds formed when two atomic nuclei share one or more pairs of electrons. Covalent bonds have spatial orientations that give molecules three-dimensional shapes. Review Figures 2.8, 2.9, 2.10, Table 2.2 Nonpolar covalent bonds are formed when the electronegativities of two atoms are approximately equal. When atoms with strong electronegativity (such as oxygen) bond to atoms with weaker electronegativity (such as hydrogen), a polar covalent bond is formed, in which one end is δ+ and the other is δ−. Review Figure 2.11, Table 2.3 Hydrogen bonds are weak electrical attractions that form between a δ+ hydrogen atom in one molecule and a δ− nitrogen or oxygen atom in another molecule or in another part of a large molecule. Hydrogen bonds are abundant in water. Review Figure 2.12 Ions are electrically charged bodies that form when an atom gains or loses one or more electrons. Ionic bonds are electrical attractions between oppositely charged ions. Ionic bonds are strong in solids, but weaker when the ions are separated from one another in solution. Review Figures 2.13, 2.14 Nonpolar molecules interact very little with polar molecules, including water. Nonpolar molecules are attracted to one another by very weak bonds called van der Waals forces. See Web/CD Tutorial 2.1 Chemical Reactions: Atoms Change Partners In chemical reactions, substances change their atomic compositions and properties. Energy is released in some reactions, whereas in others energy must be provided. Neither matter nor energy is created or destroyed in a chemical reaction, but both change form. Review Figure 2.15 In living cells, chemical reactions take place in multiple steps so that the released energy can be harvested for cellular activities. Water: Structure and Properties Water's molecular structure and its capacity to form hydrogen bonds give it unusual properties that are significant for life. Solid water floats in liquid water, and water gains or loses a great deal of heat when it changes its state, a property that moderates environmental temperature changes. Review Figure 2.16 Water's high heat of vaporization assures effective cooling when water evaporates. The cohesion of water molecules permits liquid water to rise to great heights in narrow columns and produces a high surface tension. Solutions are produced when substances dissolve in water. The concentration of a solution is the amount of a given substance in a given amount of solution. Most biological substances are dissolved in water at very low concentrations. Acids, Bases, and the pH Scale Acids are substances that donate hydrogen ions. Bases are substances that accept hydrogen ions. The pH of a solution is the negative logarithm of the hydrogen ion concentration. Values lower than pH 7 indicate an acidic solution; values above pH 7 indicate a basic solution. Review Figure 2.18 Buffers are mixtures of weak acids and bases that limit the change in the pH of a solution when acids or bases are added. Review Figure 2.19 The Properties of Molecules Functional groups make up part of a larger molecule and have particular chemical properties. The consistent chemical behavior of functional groups helps us understand the properties of the molecules that contain them. Review Figure 2.20. See Web/CD Activities

2.2, 2.3 Structural and optical isomers have the same kinds and numbers of atoms, but differ in their structures and properties. Review Figure 2.21 Molecules vary in their size, shape, reactivity, solubility, and other chemical properties. CHAPTER 3: LIFE AND CHEMISTRY: LARGE MOLECULES Theories of the Origin of Life Life may have come from outside Earth. The evidence for this proposal comes primarily from chemicals contained in meteorites that have landed on Earlth. The theory of chemical evolution proposes that life on Earth originated on Earth. Experiments using model systems that attempt to duplicate the ancient Earth have shown that chemical evolution could have produced the four types of macromolecules that distinguish living things. Review Figure 3.1. See Web/CD Tutorial 3.1 Macromolecules: Giant Polymers Macromolecules are polymers constructed by the formation of covalent bonds between smaller molecules called monomers. Macromolecules in living organisms include polysaccharides, proteins, and nucleic acids. Review Figure 3.2 and Table 3.1 Macromolecules have specific, characteristic three-dimensional shapes that depend on the structure, properties, and sequence of their monomers. Different functional groups give local sites on macromolecules specific properties that are important for their biological functioning and their interactions with other macromolecules. See Web/CD Tutorial 3.2 Condensation and Hydrolysis Reactions Monomers are joined by condensation reactions, which release a molecule of water for each bond formed. Hydrolysis reactions use water to break polymers into monomers. Review Figure 3.3 Proteins: Polymers of Amino Acids The functions of proteins include support, protection, catalysis, transport, defense, regulation, and movement. Protein function sometimes requires an attached prosthetic group. There are 20 amino acids found in proteins. Each amino acid consists of an amino group, a carboxyl group, a hydrogen, and a side chain bonded to the α carbon atom. Review Table 3.2 The side chains, or R groups, of amino acids may be charged, polar, or hydrophobic; there are also special cases, such as the —SH groups of cysteine, which can form disulfide bridges. The side chains give different properties to each of the amino acids. Review Table 3.2 and Figure 3.4 Amino acids are covalently bonded together into polypeptide chains by peptide linkages, which form by condensation reactions between the carboxyl and amino groups. Review Figure 3.5 Polypeptide chains are folded into specific three-dimensional shapes to form functional proteins. Four levels of protein structure are possible: primary, secondary, tertiary, and quaternary. The primary structure of a protein is the sequence of amino acids bonded by peptide linkages. This primary structure determines both the higher levels of structure and protein function. Review Figure 3.6a The two types of secondary structure-α helices and β pleated sheets-are maintained by hydrogen bonds between atoms of the amino acid residues. Review Figure 3.6b,c The tertiary structure of a protein is generated by bending and folding of the polypeptide chain. Review Figures 3.6d, 3.7 The quaternary structure of a protein is the arrangement of two or more polypeptides into a single functional protein consisting of two or more polypeptide subunits. Review Figures 3.6e, 3.8 Weak chemical interactions are important in the three-dimensional structure of proteins and in their binding to other molecules. Review Figure 3.9, 3.10 Proteins denatured by heat, alterations in pH, or certain chemicals lose their tertiary and secondary structure as well as their biological function. Renaturation is not often possible. Review Figure 3.11 Chaperonins assist protein folding by preventing binding to inappropriate ligands. Review Figure 3.12

Carbohydrates: Sugars and Sugar Polymers All carbohydrates contain carbon bonded to hydrogen atoms and hydroxyl groups. Hexoses are monosaccharides that contain six carbon atoms. Examples of hexoses include glucose, galactose, and fructose, which can exist as chains or rings. Review Figures 3.13, 3.14. See Web/CD Activity 3.1 The pentoses are five-carbon monosaccharides. Two pentoses, ribose and deoxyribose, are components of the nucleic acids RNA and DNA, respectively. Review Figure 3.14 Glycosidic linkages may have either α or β orientation in space. They covalently link monosaccharides into larger units such as disaccharides, oligosaccharides, and polysaccharides. Review Figure 3.15 Cellulose, a very stable glucose polymer, is the principal component of the cell walls of plants. It is formed by glucose units linked together by β-glycosidic linkages between carbons 1 and 4. Starches, less dense and less stable than cellulose, store energy in plants. Starches and glycogen are formed by α-glycosidic linkages between carbons 1 and 4 and are distinguished by the amount of branching they exhibit. Review Figure 3.16 Chemically modified monosaccharides include the sugar phosphates and amino sugars. A derivative of the amino sugar glucosamine polymerizes to form the polysaccharide chitin, which is found in the cell walls of fungi and the exoskeletons of insects. Review Figure 3.17 Lipids: Water-Insoluble Molecules Although lipids can form gigantic structures, these aggregations are not chemically macromolecules because the individual units are not linked by covalent bonds. Fats and oils are triglycerides, composed of three fatty acids covalently bonded to a glycerol molecule by ester linkages. Review Figure 3.18 Saturated fatty acids have a hydrocarbon chain with no double bonds. The hydrocarbon chains of unsaturated fatty acids have one or more double bonds that bend the chain, making close packing less possible. Review Figure 3.19 Phospholipids have a hydrophobic hydrocarbon "tail" and a hydrophilic phosphate "head." Review Figure 3.20 In water, the interactions of the hydrophobic tails and hydrophilic heads of phospholipids generate a phospholipid bilayer that is two molecules thick. The head groups are directed outward, where they interact with the surrounding water. The tails are packed together in the interior of the bilayer. Review Figure 3.21 Carotenoids trap light energy in green plants. Carotene can be split to form vitamin A, a lipid vitamin. Review Figure 3.22 Some steroids, such as testosterone, function as hormones. Cholesterol is synthesized by the liver and has a role in cell membranes, as well as in the digestion of fats. Review Figure 3.23 Vitamins are substances that are required for normal functioning, but must be acquired from the diet. Nucleic Acids: Informational Macromolecules DNA is the hereditary material. Both DNA and RNA play roles in the formation of proteins. Information flows from DNA to RNA to protein. Nucleic acids are polymers made up of nucleotides. A nucleotide consists of a phosphate group, a sugar (ribose in RNA and deoxyribose in DNA), and a nitrogen-containing base. In DNA the bases are adenine, guanine, cytosine, and thymine, but in RNA uracil substitutes for thymine. Review Figure 3.24 and Table 3.3. See Web/CD Activity 3.2 In the nucleic acids, the bases extend from a sugar-phosphate backbone. The information content of DNA and RNA resides in their base sequences. RNA is single-stranded. DNA is a double-stranded helix in which there is complementary, hydrogen-bonded base pairing between adenine and thymine (A-T) and guanine and cytosine (G-C). The two strands of the DNA double helix run in opposite directions. Review Figures 3.25, 3.27. See Web/CD Activity 3.3 Base pairing of single-stranded RNAs can lead to three-

dimensional structures, which can be catalytic. This finding has led to the proposal that in the origin of life, RNA preceded protein. Review Figure 3.26 Comparing the DNA base sequences of different living species provides information on their evolutionary relationships. All Life from Life One of the earliest conclusions from biology as a modern experimental science was that even the tiniest microbe comes from others of the same type-that is, that life begets life. Review Figure 3.28. See Web/CD Tutorial 3.3 The conditions on primeval Earth that may have enabled life to arise from inanimate self-replicating chemicals no longer exist. Today all life comes from pre-existing life. CHAPTER 4: CELLS: THE BASIC UNITS OF LIFE The Cell: The Basic Unit of Life All cells come from preexisting cells and have certain processes, types of molecules, and structures in common. The first cells may have arisen from aggregates of macromolecules in bubbles. Review Figure 4.1 To maintain adequate exchanges with its environment, a cell's surface area must be large compared with its volume. Review Figures 4.2, 4.3. See Web/CD Activity 4.1 Cells can be visualized by various methods using microscopes. Review Figure 4.4. See Web/CD Activity 4.2 All cells are surrounded by a plasma membrane. Prokaryotic Cells All prokaryotic cells have a plasma membrane, a nucleoid region with DNA, and a cytoplasm that contains ribosomes, water, and dissolved proteins and small molecules. Review Figure 4.5 Some prokaryotes have additional protective structures: cell wall, outer membrane, and capsule. Some prokaryotes contain photosynthetic membranes or mesosomes, and some have flagella or pili. Review Figure 4.6 Eukaryotic Cells Like prokaryotic cells, eukaryotic cells have a plasma membrane, cytoplasm, and ribosomes. However, eukaryotic cells are larger and contain many membrane-enclosed organelles. Review Figure 4.7 (left), 4.7 (right). See Web/CD Tutorial 4.1 The membranes that envelop organelles in the eukaryotic cell are partial barriers, ensuring that the chemical composition of the interior of the organelle differs from that of the surrounding cytoplasm. Organelles can be isolated by cell fractionation. Review Figure 4.8 Organelles that Process Information The nucleus is usually the largest organelle in a cell. It is surrounded by a double membrane, the nuclear envelope, which disassembles during cell division. Within the nucleus, the nucleolus is the source of the ribosomes found in the cytoplasm. Nuclear pores have a complex structure. Review Figure 4.9 The nucleus contains most of the cell's DNA, which associates with protein to form chromatin. Chromatin is diffuse throughout the nucleus until just before cell division, when it condenses to form chromosomes. Review Figure 4.10 The Endomembrane System The endomembrane system is made up of a series of interrelated compartments enclosed by membranes. The rough endoplasmic reticulum has attached ribosomes that synthesize proteins. The smooth endoplasmic reticulum lacks ribosomes and is associated with the synthesis of lipids. Review Figures 4.7, 4.11 The Golgi apparatus receives materials from the rough ER by means of vesicles that fuse with its cis region. Vesicles originating from the trans region of the Golgi contain proteins targeted to different cellular locations. Some of these vesicles fuse with the plasma membrane and release their contents outside the cell. Review Figures 4.7, 4.12. See Web/CD Tutorial 4.2 Lysosomes contain many digestive enzymes. Lysosomes fuse with the phagosomes produced by phagocytosis to form secondary lysosomes, in which engulfed materials are digested. Undigested materials are secreted from the cell when the secondary lysosome fuses with the plasma membrane. Review Figure 4.13.

See Web/CD Activity 4.3 Organelles that Process Energy Mitochondria are enclosed by an outer membrane and an inner membrane that folds inward to form cristae. Mitochondria contain the proteins needed for cellular respiration. Review Figure 4.14 The cells of photosynthetic eukaryotes contain chloroplasts. These organelles are enclosed by double membranes and contain an internal system of thylakoids organized as grana. Review Figures 4.7, 4.15 Thylakoids within chloroplasts contain the chlorophyll and proteins that harvest light energy for photosynthesis. Both mitochondria and chloroplasts contain their own DNA and ribosomes and are capable of making some of their own proteins. The endosymbiosis theory of the evolutionary origin of mitochondria and chloroplasts states that these organelles originated when larger prokaryotes engulfed, but did not digest, smaller prokaryotes. Mutual benefits permitted this symbiotic relationship to be maintained, allowing the smaller cells to evolve into the eukaryotic organelles observed today. Review Figure 4.18 Other Organelles Peroxisomes and glyoxysomes contain special enzymes and carry out specialized chemical reactions inside the cell. Review Figure 4.19 Vacuoles are prominent in many plant cells and consist of a membrane-enclosed compartment full of water and dissolved substances. By taking in water, vacuoles enlarge and provide the pressure needed to stretch the cell wall and provide structural support for the plant. Review Figure 4.20 The Cytoskeleton The cytoskeleton within the cytoplasm of eukaryotic cells provides shape, strength, and movement. It consists of three interacting types of protein fibers. Review Figure 4.21 Microfilaments consist of two chains of actin units that together form a double helix. Microfilaments strengthen cellular structures and provide the movement in animal cell division, cytoplasmic streaming, and pseudopod extension. Microfilaments may be found as individual fibers, bundles of fibers, or networks of fibers joined by linking proteins. Review Figures 4.21, 4.22 Intermediate filaments are formed of keratins and are organized into tough, ropelike structures that hold organelles in place within the celland add strength to cell attachments in multicellular organisms. Review Figure 4.21 Microtubules are composed of dimers of the protein tubulin. They can lengthen and shorten by adding and losing tubulin dimers. They are involved in the structure and function of cilia and flagella, both of which have a characteristic "9 + 2" pattern of microtubules. Review Figures 4.21, 4.23 The movements of cilia and flagella result from the binding of the motor protein dynein to the microtubules. Dynein and another motor protein, kinesin, also bind to microtubules to move organelles through the cell. Review Figure 4.24 Centrioles, made up of triplets of microtubules, are involved in the distribution of chromosomes during cell division. Extracellular Structures Materials external to the plasma membrane provide protection, support, and attachment for cells in multicellular systems. The cell walls of plants consist principally of cellulose. They are pierced by plasmodesmata that join the cytoplasm of adjacent cells. Review Figure 4.25 In multicellular animals, the extracellular matrix consists of different kinds of proteins, including proteoglycans. In bone and cartilage, the protein collagen predominates. Review Figure 4.26

CHAPTER 5: CELLULAR MEMBRANES Membrane Composition and Structure Biological membranes consist of lipids, proteins, and carbohydrates. The fluid mosaic model of membrane structure describes a phospholipid bilayer in which proteins can move about laterally within the membrane. Review Figures 5.1, 5.2. See Web/CD Activity 5.1 Integral membrane proteins are at least partially inserted into the phospholipid bilayer. Peripheral membrane proteins are attached to the surface of the bilayer by ionic bonds. Review Figure 5.1, 5.3, 5.4 The two surfaces of a membrane may have different properties because of their different phospholipid composition, exposed domains of integral membrane proteins, and peripheral membrane proteins. Review Figures 5.1, 5.2 Carbohydrates attached to proteins or phospholipids project from the external surface of the plasma membrane and function as recognition signals for interactions between cells. Review Figure 5.1 Cell Recognition and Adhesion Some organisms consist of a single cell, but many are multicellular. The assembly of cells into tissues requires that they recognize and adhere to one another. Recognition and adhesion depend on membrane proteins that protrude from the cell surface. Review Figure 5.5 Tight junctions prevent the passage of molecules through the spaces between cells, and they define functional regions of the plasma membrane by restricting the migration of membrane proteins uniformly over the cell surface. Desmosomes allow cells to adhere strongly to one another. Gap junctions provide channels for chemical and electrical communication between adjacent cells. Review Figure 5.6. See Web/CD Activity 5.2 Passive Processes of Membrane Transport Substances can diffuse passively across a membrane by three processes: unaided diffusion through the phospholipid bilayer, facilitated diffusion through protein channels, or facilitated diffusion by means of a carrier protein. Review Table 5.1 A solute diffuses across a membrane from a region with a greater concentration of that solute to a region with a lesser concentration of that solute. Equilibrium is reached when the concentrations of the solute are identical on both sides of the membrane. Review Figure 5.7 The rate of simple diffusion of a solute across a membrane is directly proportional to its concentration gradient across the membrane. An important factor in simple diffusion across a membrane is the lipid solubility of the solute. In osmosis, water diffuses from regions of higher water concentration to regions of lower water concentration. In hypotonic solutions, cells tend to take up water, whereas cells in hypertonic solutions tend to lose water. Animal cells must remain isotonic to the environment to prevent destructive loss or gain of water. Review Figure 5.8 (top and middle) The cell walls of plants and some other organisms prevent the cells from bursting under hypotonic conditions. The turgor pressure that develops under these conditions keeps plants upright and stretches the cell wall during plant cell growth. Review Figure 5.8 (bottom) Channel proteins and carrier proteins function in facilitated diffusion. Review Figures 5.9, 5.10, 5.11a The rate of carrier-mediated facilitated diffusion reaches a maximum when a solute concentration is reached that saturates the carrier proteins so that no increase in rate is observed with further increases in solute concentration. Review Figure 5.11b. See Web/CD Tutorial 5.1 Active Transport Active transport requires the use of chemical energy to move substances across a membrane against a concentration gradient. Review Table 5.1 Active transport proteins may be uniports, symports, or antiports. Review Figure 5.12 In primary active transport, energy from

the hydrolysis of ATP is used to move ions into or out of cells against their concentration gradients. Review Figure 5.13 Secondary active transport couples the passive movement of one solute with its concentration gradient to the movement of another solute against its concentration gradient. Energy from ATP is used indirectly to establish the concentration gradient that results in the movement of the first solute. Review Figure 5.14. See Web/CD Tutorial 5.2 Endocytosis and Exocytosis Endocytosis transports macromolecules, large particles, and small cells into eukaryotic cells by means of engulfment by and vesicle formation from the plasma membrane. Phagocytosis and pinocytosis are both nonspecific types of endocytosis. Review Figure 5.15 In receptor-mediated endocytosis, a specific membrane receptor protein binds to a particular macromolecule. Review Figure 5.16. See Web/CD Tutorial 5.3 In exocytosis, materials in vesicles are secreted from the cell when the vesicles fuse with the plasma membrane. Membranes Are Not Simply Barriers Membranes function as sites for recognition and initial processing of extracellular signals, for energy transformations, and for organizing chemical reactions. Review Figure 5.17 Membranes Are Dynamic Modifications in membrane composition accompany the conversions of one type of membrane into another type. CHAPTER 6: ENERGY, ENZYMES, AND METABOLISM Energy and Energy Conversions Energy is the capacity to do work. Potential energy is the energy of state or position; it includes the energy stored in chemical bonds. Kinetic energy is the energy of motion (and related forms such as electric energy, light, and heat). Potential energy can be converted to kinetic energy, which can do work. Review Figure 6.1 Living things, like everything else, obey the laws of thermodynamics. The first law of thermodynamics tells us that energy cannot be created or destroyed. The second law of thermodynamics tells us that the quantity of energy available to do work (free energy) decreases and unusable energy (associated with entropy) increases. Review Figure 6.2 Changes in free energy, total energy, temperature, and entropy are related by the equation $\Delta G = \Delta H - T\Delta S$. Exergonic reactions release free energy and have a negative ΔG. Endergonic reactions take up free energy and have a positive ΔG. Endergonic reactions proceed only if free energy is provided. Review Figure 6.3 The change in free energy (ΔG) of a reaction determines its point of chemical equilibrium, at which the forward and reverse reactions proceed at the same rate. For exergonic reactions, the equilibrium point lies toward completion (the conversion of all reactants into products). Review Figure 6.4 ATP: Transferring Energy in Cells ATP (adenosine triphosphate) serves as an energy currency in cells. Hydrolysis of ATP releases a relatively large amount of free energy. Review Figure 6.5 The ATP cycle couples exergonic and endergonic reactions, transferring free energy from the exergonic to the endergonic reaction. Review Figures 6.6, 6.7. See Web/CD Activity 6.1 Enzymes: Biological Catalysts The rate of a chemical reaction is independent of ΔG, but is determined by the size of the energy barrier. Catalysts speed reactions by lowering the energy barrier. Review Figures 6.8, 6.9 Enzymes are biological catalysts, proteins that are highly specific for their substrates. Substrates bind to the active site, where catalysis takes place, forming an enzyme-substrate complex. Review Figure 6.10 At the active site, a substrate can be oriented correctly, chemically modified, or strained. As a result, the substrate readily forms its transition state, and the reaction proceeds. Review Figures 6.11, 6.12. See Web/CD Activity 6.2 Molecular Structure Determines Enzyme Function The active

site where substrate binds determines the specificity of an enzyme. Upon binding to substrate, some enzymes change shape, facilitating catalysis. Review Figures 6.13, 6.14 Some enzymes require cofactors to carry out catalysis. Prosthetic groups are permanently bound to the enzyme. Coenzymes are not usually bound to the enzyme. They can be considered substrates, as they are changed by the reaction and then released from the enzyme. Review Table 6.1 and Figure 6.15 Substrate concentration affects the rate of an enzyme-catalyzed reaction. Review Figure 6.16 Metabolism and the Regulation of Enzymes Metabolism is organized into pathways in which the product of one reaction is a reactant for the next reaction. Each reaction in the pathway is catalyzed by an enzyme. Enzyme activity is subject to regulation. Some inhibitors react irreversibly with enzymes and block their catalytic activity. Others react reversibly with enzymes, inhibiting their action only temporarily. A compound closely similar in structure to an enzyme's normal substrate may competitively inhibit the action of the enzyme. Review Figures 6.17, 6.18. See Web/CD Tutorial 6.1 Allosteric regulators bind to a site different from the active site and stabilize the active or inactive form of an enzyme. Many such enzymes have multiple subunits. Review Figure 6.19. See Web/CD Tutorial 6.2 For allosteric enzymes, plots of reaction rate versus substrate concentration are sigmoid, in contrast to plots of the same variables for nonallosteric enzymes. Review Figure 6.20 The end product of a metabolic pathway may inhibit the allosteric enzyme that catalyzes the commitment step of that pathway. Review Figure 6.21 Enzymes are sensitive to their environment. Both pH and temperature affect enzyme activity. Review Figures 6.22, 6.23 CHAPTER 7: CELLULAR PATHWAYS THAT HARVEST CHEMICAL ENERGY Energy and Electrons from Glucose Metabolic pathways occur in small steps, each catalyzed by a specific enzyme. They are often compartmentalized. When glucose burns, energy is released as heat and light. The same equation applies to the metabolism of glucose by cells, but the reaction is accomplished in many separate steps so that the energy can be captured in ATP. Review Figure 7.1 Oxidation is the loss of electrons; reduction is the gain of electrons. As a material is oxidized, the electrons it loses are transferred to another material, which is thereby reduced. Such redox reactions transfer large amounts of energy. Review Figure 7.2 The coenzyme NAD is a key electron carrier in biological redox reactions. It exists in two forms, one oxidized (NAD^+) and the other reduced ($NADH + H^+$). Review Figures 7.3, 7.4 Glycolysis operates in the presence or absence of O_2. Under aerobic conditions, cellular respiration continues the process of breaking down glucose. Under anaerobic conditions, fermentation occurs. Review Figure 7.5. See Web/CD Activity 7.1 Cellular respiration consists of three pathways: pyruvate oxidation, the citric acid cycle, and the respiratory chain. Pyruvate oxidation and the citric acid cycle produce CO_2 and hydrogen atoms carried by NADH and $FADH_2$. The respiratory chain combines these hydrogens with O_2, releasing enough energy for the synthesis of ATP. Review Figure 7.5 In eukaryotes, glycolysis and fermentation take place in the cytoplasm outside of the mitochondria; pyruvate oxidation, the citric acid cycle, and the respiratory chain operate in association with mitochondria. In prokaryotes, glycolysis, fermentation, and the citric acid cycle take place in the cytoplasm, and pyruvate oxidation and the respiratory chain operate in association with the plasma membrane. Review Table 7.1. See Web/CD Activity 7.2 Glycolysis: From Glucose to Pyruvate Glycolysis is a pathway of ten enzyme-catalyzed reactions located in the

cytoplasm. Glycolysis provides starting materials for both cellular respiration and fermentation. Review Figure 7.6 The energy-investing reactions of glycolysis use two ATPs per glucose molecule and eventually yield two G3P molecules. In the energy-harvesting reactions, two NADH molecules are produced, and four ATP molecules are generated by substrate-level phosphorylation. Two pyruvate molecules are produced for each glucose molecule. Review Figures 7.6, 7.7 Pyruvate Oxidation The pyruvate dehydrogenase complex catalyzes three reactions: (1) Pyruvate is oxidized to an acetyl group, releasing one CO_2 molecule and considerable energy. (2) Some of this energy is captured when NAD^+ is reduced to NADH + H^+. (3) The remaining energy is captured when the acetyl group is combined with coenzyme A, yielding acetyl CoA. The Citric Acid Cycle The energy in acetyl CoA drives the reaction of acetate with oxaloacetate to produce citrate. The citric acid cycle is a series of reactions in which citrate is oxidized and oxaloacetate regenerated (hence a "cycle"). It produces 2 CO_2, 1 $FADH_2$, 3 NADH, and 1 ATP for each acetyl CoA. Review Figures 7.8, 7.9. See Web/CD Activity 7.3 The Respiratory Chain: Electrons, Proton Pumping, and ATP Production NADH and $FADH_2$ from glycolysis, pyruvate oxidation, and the citric acid cycle are oxidized by the respiratory chain, regenerating NAD^+ and FAD. Most of the enzymes and other electron carriers of the chain are part of the inner mitochondrial membrane. Oxygen (O_2) is the final acceptor of electrons and protons, forming water (H_2O). Review Figures 7.10, 7.11. See Web/CD Activity 7.4 The chemiosmotic mechanism couples proton transport to oxidative phosphorylation. As the electrons move along the respiratory chain, protons are pumped out of the mitochondrial matrix, establishing a gradient of both proton concentration and electric charge-the proton-motive force. Review Figure 7.12. See Web/CD Tutorial 7.1 The proton-motive force causes protons to diffuse back into the mitochondrial matrix through the membrane channel protein ATP synthase, which couples that diffusion to the production of ATP. Several key experiments demonstrate that chemiosmosis produces ATP. Review Figure 7.13. See Web/CD Tutorial 7.2 Fermentation: ATP from Glucose, without O_2 Many organisms and some cells live without O_2, deriving all their energy from glycolysis and fermentation. Together, these pathways partly oxidize glucose and generate energy-containing products such as lactic acid or ethanol. Review Figures 7.14, 7.15 Contrasting Energy Yields For each molecule of glucose used, fermentation yields 2 molecules of ATP. In contrast, glycolysis operating with pyruvate oxidation, the citric acid cycle, and the respiratory chain yields up to 36 molecules of ATP per molecule of glucose. Review Figure 7.16. See Web/CD Activity 7.5 Relationships between Metabolic Pathways Catabolic pathways feed into the energy-harvesting metabolic pathways. Polysaccharides are broken down into glucose, which enters glycolysis. Glycerol from fats also enters glycolysis, and acetyl CoA from fatty acid degradation enters the citric acid cycle. Proteins enter glycolysis and the citric acid cycle via amino acids. Review Figures 7.17, 7.18 Anabolic pathways use intermediate components of energy-harvesting pathways to synthesize fats, amino acids, and other essential building blocks. Review Figures 7.17, 7.18 Regulating Energy Pathways The rates of glycolysis and the citric acid cycle are increased or decreased by the actions of ATP, ADP, NAD^+, or NADH + H^+ on allosteric enzymes. Inhibition of the glycolytic enzyme phosphofructokinase by abundant ATP from cellular respiration slows down glycolysis. ADP activates this enzyme, speeding up glycolysis. The citric

acid cycle enzyme isocitrate dehydrogenase is inhibited by ATP and NADH and activated by ADP and NAD+. Review Figures 7.19, 7.20. See Web/CD Activity 7.6 CHAPTER 8: PHOTOSYNTHESIS: ENERGY FROM THE SUN Identifying Photosynthetic Reactants and Products Photosynthesizing plants take in CO_2, water, and light energy, producing O_2 and carbohydrates. The overall reaction is $6\ CO_2 + 12\ H_2O + \text{light} \rightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$ The oxygen atoms in the O_2 produced by photosynthesis come from water, not from CO_2. Review Figures 8.1, 8.2. See Web/CD Tutorial 8.1 The Two Pathways of Photosynthesis: An Overview In plants, photosynthesis takes place in chloroplasts. In the light reactions of photosynthesis, electron transport and photophosphorylation produce ATP and reduce NADP+ to NADPH + H+. Review Figure 8.3 ATP and NADPH + H+ are needed for the reactions that fix and reduce CO_2 in the Calvin-Benson cycle, forming carbohydrates. Review Figure 8.3 The Interactions of Light and Pigments Light energy comes in packets called photons, but it also has wavelike properties. Absorption of a photon puts a pigment molecule in an excited state that has more energy than its ground state. Review Figure 8.4 Pigments absorb light in the visible spectrum. Review Figure 8.5 Each compound has a characteristic absorption spectrum. An action spectrum reveals the biological effectiveness of different wavelengths of light. The absorption spectrum of the plant pigment chlorophyll a correlates well with the action spectrum for photosynthesis. Review Figure 8.6 Chlorophylls and accessory pigments form antenna systems for absorption of light energy. Review Figure 8.7 An excited pigment molecule may lose its energy by fluorescence or by transferring it to another pigment molecule. Review Figure 8.8 Electron Transport, Reductions, and Photophosphorylation Noncyclic electron transport uses two photosystems (I and II) and produces ATP, NADPH + H+, and O_2. Photosystem II uses P680 chlorophyll, from which light-excited electrons are passed to a redox chain that drives chemiosmotic ATP production. Light-driven oxidation of water releases O_2 and passes electrons from water to the P680 chlorophyll. Photosystem I passes electrons from P700 chlorophyll to another redox chain and then to NADP+, forming NADPH + H+. Review Figure 8.9 Cyclic electron transport uses P700 chlorophyll and produces only ATP. Its operation maintains the proper balance of ATP and NADPH + H+ in the chloroplast. Review Figure 8.10 Chemiosmosis is the mechanism of ATP production in photophosphorylation. Electron transport pumps protons from the stroma into the thylakoids. Diffusion of the protons back to the stroma via ATP synthase channels drives ATP formation. Review Figure 8.11. See Web/CD Tutorial 8.2 Making Carbohydrate from CO_2: The Calvin-Benson Cycle The Calvin-Benson cycle makes sugar from CO_2. This pathway was elucidated through the use of radioactive tracers. Review Figure 8.12. See Web/CD Tutorial 8.3 The Calvin-Benson cycle consists of three phases: fixation of CO_2, reduction and carbohydrate production, and regeneration of RuBP. RuBP is the initial CO_2 acceptor, and 3PG is the first stable product of CO_2 fixation. The enzyme rubisco catalyzes the reaction of CO_2 and RuBP to form 3PG. Review Figures 8.13, 8.14. See Web/CD Activity 8.1 Photorespiration and Its Consequences The enzyme rubisco can catalyze a reaction between O_2 and RuBP in addition to the reaction between CO_2 and RuBP. This reaction with O_2 is called photorespiration and significantly reduces the efficiency of photosynthesis. The reactions that constitute photorespiration are distributed over three organelles: chloroplasts, peroxisomes, and mitochondria. Review Figure 8.15 At high temperatures and low CO_2

concentrations, the oxygenase function of rubisco is favored. C4 plants bypass photorespiration with special chemical reactions and specialized leaf anatomy. In C4 plants, PEP carboxylase in chloroplasts of the mesophyll cells initially fixes CO2 in a four-carbon compound, which then diffuses into bundle sheath cells, where its decarboxylation produces locally high concentrations of CO2. Review Figures 8.16, 8.17. See Web/CD Activity 8.2 CAM plants operate much like C4 plants, but their initial CO2 fixation by PEP carboxylase is temporally separated from the Calvin-Benson cycle, rather than spatially separated as in C4 plants. Metabolic Pathways in Plants Photosynthesis and respiration are linked through the Calvin-Benson cycle, the citric acid cycle, and glycolysis. Review Figure 8.18 To survive, a plant must photosynthesize more than it respires.

CHAPTER 9: CHROMOSOMES, THE CELL CYCLE, AND CELL DIVISION Systems of Cell Reproduction Cell division is necessary for the reproduction, growth, and repair of an organism. Review Figure 9.1 Cell division must be initiated by a reproductive signal. Cell division consists of three steps: replication of the genetic material (DNA), segregation of the two DNA molecules to separate portions of the cell, and cytokinesis, or division of the cytoplasm. In prokaryotes, cellular DNA is a single molecule, or chromosome. Prokaryotes reproduce by cell fission. Review Figure 9.2 In eukaryotes, cells divide by either mitosis or meiosis. Interphase and the Control of Cell Division The mitotic cell cycle has two main phases: interphase (during which cells are not dividing) and mitosis (when cells are dividing). During most of the cell cycle, the cell is in interphase, which is divided into three subphases: S, G1, and G2. DNA is replicated during the S phase. Review Figure 9.3 Cyclin-Cdk complexes regulate the passage of cells through checkpoints in the cell cycle. The most important one is the R point in G1, which determines whether the rest of the cycle will proceed. Review Figure 9.4 In addition to the internal cyclin-Cdk complexes, controls external to the cell, such as growth factors and hormones, can also stimulate the cell to begin a division cycle. Eukaryotic Chromosomes A eukaryotic chromosome contains a DNA molecule bound to proteins in a complex called chromatin. At mitosis, the replicated chromatids are held together at the centromere. Each chromatid consists of one double-stranded DNA molecule. Review Figure 9.5 During interphase, the DNA in chromatin is wound around cores of histones to form nucleosomes. DNA folds over and over again, packing itself within the nucleus. During mitosis or meiosis, it folds even more. Review Figure 9.6 Mitosis: Distributing Exact Copies of Genetic Information After DNA is replicated during the S phase, the first sign of mitosis is the separation of the replicated centrosomes, which initiate microtubule formation for the spindle. Mitosis can be divided into several phases, called prophase, prometaphase, metaphase, anaphase, and telophase. During prophase, the chromosomes condense and appear as paired chromatids, and the spindle forms. Review Figure 9.7. See Web/CD Activity 9.1 During prometaphase, the chromosomes move toward the middle of the spindle. In metaphase, they gather at the middle of the cell with their centromeres on the equatorial plate. At the end of metaphase, the centromeres holding the sister chromatids together separate, and during anaphase, each chromatid, now called the daughter chromosome, migrates to its pole along

the microtubule track. Review Figure 9.8 (left) and 9.8 (right). See Web/CD Activity 9.2 Cohesin holds sister chromatids together from the time they are formed in DNA replication until the onset of anaphase. Separin hydrolyzes cohesin when an inhibitory subunit, securin, is hydrolyzed. Review Figure 9.9 During telophase, the chromosomes become less condensed. The nuclear envelopes and nucleoli re-form, thus producing two nuclei whose chromosomes are identical to each other and to those of the cell that began the cycle. See Web/CD Tutorial 9.1 Cytokinesis: The Division of the Cytoplasm Nuclear division is usually followed by cytokinesis. Animal cell cytoplasm usually divides by a furrowing of the plasma membrane, caused by the contraction of cytoplasmic microfilaments. In plant cells, cytokinesis is accomplished by vesicle fusion and the synthesis of new cell wall material. Review Figure 9.10 Reproduction: Asexual and Sexual The cell cycle can repeat itself many times, forming a clone of genetically identical cells. Asexual reproduction produces a new organism that is genetically identical to the parent. Any genetic variety is the result of mutations. In sexual reproduction, two haploid gametes—one from each parent—unite in fertilization to form a genetically unique, diploid zygote. Review Figure 9.12. See Web/CD Activity 9.3 In sexually reproducing organisms, certain cells in the adult undergo meiosis, a process by which a diploid cell produces haploid gametes. Each gamete contains a random selection of one of each pair of homologous chromosomes from the parent. The number, shapes, and sizes of the chromosomes constitute the karyotype of an organism. Review Figure 9.13 Meiosis: A Pair of Nuclear Divisions Meiosis reduces the chromosome number from diploid to haploid, ensures that each haploid cell contains one member of each chromosome pair, and results in genetically diverse products. It consists of two nuclear divisions. Review Figure 9.14 (left) and 9.14 (right). See Web/CD Activity 9.4 During prophase I of the first meiotic division, homologous chromosomes pair up with each other, and material may be exchanged between the two homologs by crossing over. In metaphase I, the paired homologs line up at the equatorial plate. Review Figures 9.14 (left) and 9.14 (right), 9.16 In anaphase I, entire chromosomes, each with two chromatids, migrate to the poles. By the end of meiosis I, there are two nuclei, each with the haploid number of chromosomes. Review Figures 9.14 (left) and 9.14 (right), 9.17 In meiosis II, the sister chromatids separate. No DNA replication precedes this division, which in other aspects is similar to mitosis. The result of meiosis is four cells, each with a haploid chromosome content. Review Figures 9.14 (left) and 9.14 (right), 9.17 Both crossing over during prophase I and the random selection of which homolog of a pair migrates to which pole during anaphase I ensure that the genetic composition of each haploid gamete is different from that of the parent cell and from that of the other gametes. The more chromosome pairs there are in a diploid cell, the greater the diversity of chromosome combinations generated by meiosis. Review Figure 9.16, Table 9.1. See Web/CD Tutorial 9.2 Meiotic Errors In nondisjunction, one member of a homologous pair of chromosomes fails to separate from the other, and both go to the same pole. Pairs of homologous chromosomes may also fail to stick together when they should. These events may lead to one gamete with an extra chromosome and another lacking that chromosome. The union of a gamete with an abnormal chromosome number with a normal haploid gamete at fertilization results in aneuploidy and genetic abnormalities that are invariably harmful or lethal to the organism. Review Figure 9.18

Polyploid organisms can have difficulty in cell division. Natural and artificially produced polyploids underlie modern agriculture. Cell Death Cells may die by necrosis, or they may self-destruct by apoptosis, a genetically programmed series of events that includes the detachment of the cell from its neighbors and the fragmentation of its nuclear DNA. Review Figure 9.19, Table 9.2 CHAPTER 10: GENETICS: MENDEL AND BEYOND The Foundations of Genetics Although it had long been known that both parents contribute to the character traits of their offspring, before Mendel's time it was believed that, once they were brought together, the units of inheritance blended and could never be separated. Although Gregor Mendel's work was meticulous and well documented, his discoveries, reported in the 1860s, were ignored until decades later. Mendel's Experiments and the Laws of Inheritance Mendel used the garden pea for his studies because the plants were easily cultivated and crossed and because they showed numerous characters (such as seed shape) with clearly different traits (spherical or wrinkled). Review Figure 10.1, Table 10.1 In a monohybrid cross, the offspring of the first generation (F1) showed only one of the two parental traits. Mendel proposed that the trait observed in the F1 was dominant and the other was recessive. Review Table 10.1 When the F1 offspring were self-pollinated, the resulting F2 generation showed a 3:1 phenotypic ratio, with the recessive phenotype present in one-fourth of the offspring. This reappearance of the recessive phenotype refuted the blending theory. Review Figure 10.3 Because some alleles are dominant and some are recessive, the same phenotype can result from different genotypes. Homozygous genotypes have two copies of the same allele; heterozygous genotypes have two different alleles. Heterozygous genotypes yield phenotypes that show the dominant trait. On the basis of many crosses using different characters, Mendel proposed his first law: that the units of inheritance (now known as genes) are particulate, that there are two alleles of each gene in each parent, and that during gamete formation the two alleles segregate from each other. Review Figure 10.4 Geneticists who followed Mendel showed that genes are carried on chromosomes and that alleles are segregated during meiosis I. Review Figure 10.5 Using a test cross, Mendel was able to determine whether a plant showing the dominant phenotype was homozygous or heterozygous. The appearance of the recessive phenotype in half of the offspring of such a cross indicates that the parent is heterozygous. Review Figure 10.6. See Web/CD Activity 10.1 From studies of the inheritance of two characters using dihybrid crosses, Mendel concluded that alleles of different genes assort independently. Review Figures 10.7, 10.8. See Web/CD Tutorial 10.1 We can predict the results of hybrid crosses either by using a Punnett square or by calculating probabilities. To determine the joint probability of independent events, we multiply the individual probabilities. To determine the probability of an event that can occur in two or more different ways, we add the individual probabilities. Review Figure 10.9 The analysis of pedigrees can trace Mendelian inheritance patterns in humans. Review Figures 10.10, 10.11 Alleles and Their Interactions New alleles arise by mutation, and many genes have multiple alleles. Review Figure 10.12 Dominance is sometimes not complete, since both alleles in a heterozygous organism may be expressed in the phenotype. Review Figures 10.13, 10.14 Gene Interactions In epistasis, the products of different genes interact to produce a phenotype. Review Figure 10.15 Environmental variables such as temperature, nutrition, and light affect gene action. In some cases, the

phenotype is the result of the effects of several genes and the environment, and inheritance is quantitative. Review Figure 10.17 Genes and Chromosomes Each chromosome carries many genes. Genes located on the same chromosome are said to be linked, and they are often inherited together. Review Figure 10.18 Linked genes can recombine by crossing over in prophase I of meiosis. The result is recombinant gametes, which have new combinations of linked genes because of the exchange. Review Figures 10.19, 10.20 The distance between two genes on a chromosome is proportional to the frequency of crossing over between them. Genetic maps are based on recombinant frequencies. Review Figures 10.21, 10.22. See Web/CD Tutorial 10.2 Sex Determination and Sex-Linked Inheritance Sex chromosomes carry genes that determine whether the organism will produce male or female gametes. The specific functions of X and Y chromosomes differ among species. In fruit flies and mammals, the X chromosome carries many genes, but the Y chromosome has only a few. Males have only one allele for X-linked genes, so rare alleles show up phenotypically more often in males than in females. Review Figures 10.23, 10.24 Non-Nuclear Inheritance Cytoplasmic organelles such as plastids and mitochondria contain some heritable genes. Cytoplasmic organelle genes are generally inherited only from the mother because male gametes contribute only their nucleus to the zygote at fertilization. See Web/CD Activities 10.2 and 10.3 for a concept review of this chapter. CHAPTER 11: DNA AND ITS ROLE IN HEREDITY DNA: The Genetic Material Circumstantial evidence (its location and quantity in the cell) suggested that DNA might be the genetic material. Two experiments provided a convincing demonstration that this was the case. Review Figures 11.1, 11.2, 11.3 The Structure of DNA X-ray crystallography showed that the DNA molecule is a helix. Review Figure 11.4 DNA is composed of nucleotides, each containing one of four bases: adenine, cytosine, thymine, or guanine. Biochemical analysis revealed that the amount of adenine equals the amount of thymine and the amount of guanine equals the amount of cytosine. Review Figure 11.5 Putting the accumulated data together, Watson and Crick proposed that DNA is a double-stranded helix in which the strands are antiparallel and the bases are held together by hydrogen bonding. This model accounts for the genetic information, mutation, and replication functions of DNA. Review Figures 11.6, 11.7 Determining the DNA Replication Mechanism An experiment by Meselson and Stahl proved the replication of DNA to be semiconservative. Each parent strand acts as a template for the synthesis of a new strand; thus the two replicated DNA helices each contain one parent strand and one newly synthesized strand. Review Figures 11.8, 11.9. See Web/CD Tutorial 11.1 The Mechanisms of DNA Replication In DNA replication, the enzyme DNA polymerase catalyzes the addition of nucleotides to the 3′ end of each strand. Nucleotides are added by complementary base pairing with the template strand of DNA. The substrates are deoxyribonucleoside triphosphates, which are hydrolyzed as they are added to the growing chain, releasing energy that fuels the synthesis of DNA. Review Figure 11.10 The DNA replication complex is attached to nuclear structures, and DNA is threaded through it for replication. Review Figure 11.11 Many proteins assist in DNA replication. DNA helicase unwinds the double helix, and the template strands are stabilized by single-strand binding proteins. Prokaryotes have a single origin of replication; eukaryotes have many. Replication in both cases proceeds in both directions from an origin of replication. Review Figure 11.12 An RNA primase catalyzes the synthesis a short RNA primer, to which

nucleotides are added. Review Figure 11.14 Through the action of DNA polymerase, the leading strand grows continuously in the 5′-to-3′ direction until the replication of that section of DNA has been completed. Then the RNA primer is degraded and DNA is added in its place. On the lagging strand, DNA is still made in the 5′-to-3′ direction. But synthesis of the lagging strand is discontinuous: The DNA is added as short fragments to primers, then the polymerase skips past the 5′ end to make the next fragment. Review Figures 11.15, 11.16, 11.17. See Web/CD Tutorial 11.3 The very ends of linear chromosomes are usually not fully replicated because there is no place for a primer to bind on the lagging strand. This leads to a shortening of the DNA after each round of replication, and ultimately cell death. Some cells have an enzyme, telomerase, that maintains chromosome length so that the cell can continue to divide. Review Figure 11.18. See Web/CD Tutorial 11.2 DNA Proofreading and Repair The machinery of DNA replication makes about one error in 106 nucleotides bases added. DNA is also subject to chemical damage. DNA is repaired by three different mechanisms: proofreading, mismatch repair, and excision repair. Review Figure 11.19 Practical Applications of DNA Replication The polymerase chain reaction technique uses DNA polymerase to repeatedly replicate DNA in the laboratory. Review Figure 11.20 The principles of DNA replication can be used to determine the nucleotide sequence of DNA. Review Figure 11.21 CHAPTER 12: FROM DNA TO PROTEIN: GENOTYPE TO PHENOTYPE One Gene, One Polypeptide Genes are expressed in the phenotype as polypeptides (proteins). Beadle and Tatum's experiments with the bread mold Neurospora resulted in several mutant strains, each lacking a specific enzyme in a biochemical pathway. Their results led to the one-gene, one-polypeptide hypothesis. Review Figure 12.1 Certain hereditary diseases in humans had been found to be caused by the absence of certain enzymes. These observations supported the one-gene, one-polypeptide hypothesis. DNA, RNA, and the Flow of Information RNA differs from DNA in three ways: It is single-stranded, its sugar molecule is ribose rather than deoxyribose, and its fourth base is uracil rather than thymine. The central dogma of molecular biology is DNA → RNA → protein. Review Figure 12.2 A gene is expressed in two steps: first, DNA is transcribed to RNA; then RNA is translated into protein. Review Figure 12.3 Some viruses are exceptions to the central dogma. Some viruses exclude DNA altogether, going directly from RNA to protein. In retroviruses, the central dogma is reversed: RNA → DNA. Transcription: DNA-Directed RNA Synthesis RNA is transcribed from a DNA template after the bases of DNA are exposed by unwinding of the double helix. In a given gene, only one of the two strands of DNA (the template strand) acts as a template for transcription. RNA polymerase catalyzes transcription from the template strand of DNA. The initiation of transcription requires that RNA polymerase recognize and bind tightly to a promoter sequence on the DNA. RNA elongates in a 5′-to-3′ direction, antiparallel to the template DNA. Special sequences and protein helpers terminate transcription. Review Figure 12.4 In prokaryotes, translation begins before transcription of the mRNA is completed. In eukaryotes, transcription occurs in the nucleus and translation occurs in the cytoplasm. See Web/CD Tutorial 12.1 The Genetic Code The genetic code consists of triplets of nucleotide bases (codons). There are four bases, so there are 64 possible codons. One mRNA codon indicates the starting point of translation and codes for methionine. Three stop codons indicate the end of translation. The other 60 codons code only for particular amino acids. Because there

are only 20 different amino acids, the genetic code is redundant; that is, there is more than one codon for certain amino acids. But the code is not ambiguous: A single codon does not encode more than one amino acid. Review Figure 12.5. See Web/CD Activity 12.1 Test-tube experiments led to the assignment of amino acids to codons. Review Figure 12.6. See Web/CD Tutorial 12.2 Preparation for Translation: Linking RNAs, Amino Acids, and Ribosomes In translation, amino acids are linked in an order specified by the codons in mRNA. This task is achieved by transfer RNAs (tRNAs), which bind to specific amino acids. Each tRNA species has an anticodon complementary to an mRNA codon. Review Figure 12.7 A family of activating enzymes attaches specific amino acids to their appropriate tRNAs, forming charged tRNAs. Review Figure 12.8 The mRNA meets the charged tRNAs at a ribosome. Review Figure 12.9 The small subunit of the ribosome checks to determine whether the tRNA anticodon and mRNA codon have formed hydrogen bonds. Translation: RNA-Directed Polypeptide Synthesis An initiation complex consisting of a charged tRNA and a small ribosomal subunit bound to mRNA triggers the beginning of translation. Review Figure 12.10 Polypeptides grow from the N terminus toward the C terminus. The ribosome moves along the mRNA one codon at a time in the 5′-to-3′ direction. Review Figure 12.11 The presence of a stop codon in the A site of the ribosome terminates translation. Review Figure 12.12. See Web/CD Tutorial 12.3 Regulation of Translation Some antibiotics and bacterial toxins work by blocking events in translation. Review Table 12.2 In a polysome, more than one ribosome moves along the mRNA at one time. Review Figure 12.13 Posttranslational Events Signals contained in the amino acid sequences of proteins direct them to their cellular destinations. Review Figure 12.14 Protein synthesis begins on free ribosomes in the cytoplasm. Those proteins destined for the nucleus and other organelles are completed there. These proteins have signals that allow them to bind to and enter their destined organelles. Proteins destined for the ER, Golgi apparatus, lysosomes, and outside the cell complete their synthesis on the surface of the ER. They enter the ER by the interaction of a hydrophobic signal sequence with a channel in the membrane. Review Figure 12.15 Modifications of proteins after translation include proteolysis, glycosylation, and phosphorylation. Review Figure 12.16 Mutations: Heritable Changes in Genes Mutations in DNA are often expressed as abnormal proteins. However, the result may not be easily observable phenotypic changes. Some mutations are detectable only under certain conditions. Point mutations (silent, missense, nonsense, or frame-shift) result from alterations in single base pairs of DNA. Review pages 251-252 Chromosomal mutations (deletions, duplications, inversions, or translocations) involve large regions of a chromosome. Review Figure 12.18 Mutations can be spontaneous or induced. Spontaneous mutations occur because of instabilities in DNA or chromosomes. Induced mutations occur when a mutagen damages DNA. Review Figure 12.19

CHAPTER 13: THE GENETICS OF VIRUSES AND PROKARYOTES Probing the Nature of Genes Prokaryotes and viruses are useful for the study of genetics and molecular biology because they contain much less DNA than eukaryotes, grow and reproduce rapidly, and are haploid. Viruses: Reproduction and Recombination Viruses were discovered as disease-causing agents small

enough to pass through a filter that retains bacteria. The basic viral unit, called a virion, consists of a nucleic acid genome, which codes for a few proteins, and a protein coat called a capsid. Viruses are obligate intracellular parasites: they need the biochemical machinery of a living cell in order to reproduce. There are many types of viruses, classified by their size and shape, by their genetic material (RNA or DNA), or by their host organism. Review Figure 13.1 Bacteriophage are viruses that infect bacteria. In the lytic cycle, the host cell bursts, releasing new phage particles. Some phage can also undergo a lysogenic cycle, in which their DNA is inserted into the host chromosome, where it replicates for generations. When conditions are appropriate, the phage DNA exits the host chromosome and enters a lytic cycle. Review Figure 13.2 Some viruses have promoters for host RNA polymerase, which they use to transcribe their own genes. Review Figure 13.3 Most of the many types of RNA and DNA viruses that infect animals cause diseases. Some animal viruses have an envelope derived from the host's plasma membrane. Retroviruses, such as HIV, have RNA genomes that they reproduce through a complementary DNA intermediate. Other RNA viruses use their RNA to make mRNA to code for enzymes and replicate their genomes without using DNA. Review Figures 13.4, 13.5 Many viruses are spread by vectors, such as insects. Prokaryotes: Reproduction and Recombination When bacteria divide, they form clones of identical cells that can be observed as colonies when grown on solid media. Review Figure 13.6 A bacterium can transfer its genes to another bacterium by conjugation, transformation, or transduction. In conjugation, a bacterium attaches to another bacterium and passes a fragment of its DNA to the recipient cell. Review Figures 13.7, 13.8, 13.9 In transformation, fragments of bacterial DNA are taken up by a cell from the environment. These genetic fragments may recombine with the host chromosome, thereby permanently adding new genes. Review Figure 13.10a In transduction, phage capsids carry bacterial DNA from one bacterium to another. Review Figure 13.10b Plasmids are small bacterial chromosomes that are independent of the main chromosome. R factors, which are plasmids that carry genes for antibiotic resistance, are a serious public health threat. Review Figure 13.11 Transposable elements are stretches of DNA that can move from one place to another on the bacterial chromosome–either by actually moving or by making a new copy, which is inserted at a new location. Review Figure 13.12 Regulation of Gene Expression in Prokaryotes In prokaryotes, the synthesis of some proteins is regulated so that they are made only when they are needed. Constitutive enzymes whose products are essential to the cell at all times, are synthesized constantly. A compound that stimulates the synthesis of an enzyme needed to process it is called an inducer, and the enzyme is called an inducible enzyme. Review Figures 13.13, 13.14 An operon consists of a promoter, an operator, and two or more structural genes. Promoters and operators do not code for proteins, but serve as binding sites for regulatory proteins. When a repressor protein binds to the operator, transcription of the structural genes is inhibited. Review Figures 13.15, 13.16 The mechanisms that regulate the expression of prokaryotic genes include inducible operator–repressor systems, repressible operator–repressor systems, and systems that increase the efficiency of a promoter. Review Table 13.2 The lac operon is an example of an inducible system. When lactose is absent, a repressor protein binds tightly to the operator. The repressor prevents RNA polymerase from binding to the promoter, turning transcription off. Lactose acts as an

inducer by binding to the repressor. This binding changes the repressor's shape so that it can no longer bind to the operator. With the operator unbound, RNA polymerase binds to the promoter, and transcription is turned on. Review Figure 13.17. See Web/CD Tutorial 13.1 Repressor proteins are coded by constitutive regulatory genes. The trp operon is an example of a repressible system. The presence of tryptophan, the end product of a metabolic pathway, represses synthesis of the enzymes involved in that pathway. Tryptophan acts as a corepressor by binding to an inactive repressor protein and making it active. When the activated repressor binds to the operator, transcription is turned off. Review Figure 13.18. See Web/CD Tutorial 13.2 The efficiency of a promoter can be increased by regulation of the level of cAMP, which binds to a protein called CRP. The CRP-cAMP complex then binds to a site near the promoter, enhancing the effectiveness of RNA polymerase binding and hence transcription. Review Figure 13.19 Control of Transcription in Viruses In bacteriophage that can undergo a lytic or a lysogenic cycle, the decision as to which pathway to take is made by operator–regulatory protein interactions. Review Figure 13.20 Prokaryotic Genomes Functional genomics relates gene sequences to protein functions. Review Figure 13.21 By mutating individual genes in a small genome, scientists can determine the minimal genome required for cellular life. Review Figure 13.22. See Web/CD Activity 13.1 for a concept review of this chapter. CHAPTER 14: THE EUKARYOTIC GENOME AND ITS EXPRESSION The Eukaryotic Genome Although eukaryotes have more DNA in their genomes than prokaryotes, there is no apparent relationship between genome size and organism complexity within eukaryotes. There are many differences between prokaryotic and eukaryotic genomes and their mechanisms of expression. Review Table 14.1 Unlike prokaryotic DNA, eukaryotic DNA is contained within a nucleus, so that transcription and translation are physically separated. Review Figure 14.1. See Web/CD Activity 14.1 The genome of the single-celled budding yeast contains genes for the same metabolic machinery found in prokaryotes, with the addition of genes for protein targeting in the cell. Review Table 14.2 The genome of the multicellular roundworm Caenorhabditis elegans contains genes required for intercellular interactions. Review Table 14.3 The genome of the fruit fly has fewer genes than that of the roundworm. Many of its genes are homologs of genes found in the roundworm and mammalian genomes. The puffer fish genome is the most compact vertebrate genome known. The compact genome of the simple plant Arabidopsis is often used in the study of plant genomes. Review Table 14.4 The rice genome is similar to that of Arabidopsis, and its sequence holds a key to feeding the increasing human population. Review Table 14.5 Repetitive Sequences in the Eukaryotic Genome Highly repetitive DNA is present in up to millions of copies of short sequences. It is not transcribed. Some moderately repetitive DNA sequences, such as those that code for rRNAs, are transcribed. Review Figure 14.2 Some moderately repetitive DNA sequences are transposons, which are able to move about the genome. Review Figure 14.3 The Structures of Protein-Coding Genes A typical eukaryotic protein-coding gene is flanked by promoter and terminator sequences and contains noncoding internal sequences, called introns. Review Figure 14.4 Nucleic acid hybridization is an important technique for analyzing eukaryotic genes. Review Figure 14.5, 14.6 Some eukaryotic genes exist as families of related genes, which have similar sequences and code for similar proteins. These related proteins may be made at different times and in different tissues. Some

sequences in gene families are pseudogenes, which code for nonfunctional mRNAs or proteins. Review Figure 14.7 Differential expression of different genes in the β-globin cluster of the globin family ensures important physiological changes during human development. Review Figure 14.8 RNA Processing The transcribed pre-mRNA is altered by the addition of a G cap at the 5′ end and a poly A tail at the 3′ end. Review Figure 14.9 The introns are removed from the mRNA precursor by the spliceosome, a complex of snRNPs and proteins. Review Figure 14.10. See Web/CD Tutorial 14.1 Transcriptional Regulation of Gene Expression Eukaryotic gene expression can be regulated at the transcriptional, posttranscriptional, translational, and posttranslational levels. Review Figure 14.11. See Web/CD Activity 14.2 The major method of regulation of eukaryotic gene expression is selective transcription, which results from the binding of specific proteins to regulatory sequences on DNA. A series of transcription factors must bind to one another to form a transcription complex before RNA polymerase can bind. Whether RNA polymerase initiates transcription also depends on the binding of regulator proteins, activator proteins (which bind to enhancers and stimulate transcription), and repressor proteins (which bind to silencers and inhibit transcription). Review Figures 14.12, 14.13. See Web/CD Tutorial 14.2 The simultaneous regulation of widely separated genes is possible through common sequences in their promoters, to which the same regulatory proteins bind. Review Figure 14.14 The DNA-binding domains of most DNA-binding proteins have one of four structural motifs: helix-turn-helix, zinc finger, leucine zipper, or helix-loop-helix. Review Figure 14.15 Chromatin remodeling allows the transcription complex to bind DNA and to move through the nucleosomes. Review Figure 14.16 Heterochromatin is a condensed form of DNA that cannot be transcribed. It is found in the inactive X chromosome of female mammals. Review Figure 14.17 Interference RNA (RNAi) is important in inhibiting transcription of the inactive X chromosome. Review Figure 14.18 The movement of a gene to a new location on a chromosome may alter its ability to be transcribed, as in the change from one mating type to another in budding yeast. Some genes are selectively amplified in some cells. The extra copies of these genes result in increased transcription of their protein product. Review Figure 14.19 Posttranscriptional Regulation Alternative splicing of pre-mRNA can be used to produce different proteins. The transcripts of over half the genes in the human genome are alternatively spliced, which increases the number of proteins that can be encoded by a single gene. Review Figure 14.20 The stability of mRNA in the cytoplasm can be regulated. Mature mRNA can be edited by the addition of new nucleotides or by the alteration of existing nucleotides. Review Figure 14.21 Translational and Posttranslational Regulation Translational repressors can inhibit the translation of mRNA. Proteasomes degrade proteins targeted for breakdown by attachment of ubiquitin. Review Figure 14.22 CHAPTER 15: CELL SIGNALING AND COMMUNICATION Signals Cells receive many signals from the physical environment and from other cells. Review Figure 15.1 A signal transduction pathway involves three steps: the binding of a signal by a receptor, the transduction of the signal within the cell, and the ultimate cellular response. Review Figure 15.2. See Web/CD Activity 15.1 Receptors Cells respond to signals only if they have specific receptor proteins that can bind to those signals. Review Figure 15.3 Depending on the nature of its signal, a receptor may be located in the plasma membrane or in the cytoplasm of the target cell. Review Figure 15.4

Receptors located in the plasma membrane include ion channels, protein kinases, and G protein-linked receptors. Review Figures 15.5, 15.6, 15.7. See Web/CD Tutorial 15.1 When bound by a ligand, cytoplasmic receptors change their shape and enter the cell nucleus. Review Figure 15.8 Signal Transduction The events of signal transduction may be direct, occurring at the plasma membrane, or indirect, involving the formation of a second messenger. Protein kinase cascades amplify a response to receptor binding. Review Figure 15.9 Second messengers include cyclic AMP, the lipid-derived substances inositol triphosphate and diacylglycerol, calcium ions, and the gas nitric oxide. Review Figures 15.10, 15.11, 15.12, 15.13 Signal Effects: Changes in Cell Function The ultimate cell response to a signal may be the opening of ion channels, the alteration of enzyme activities, or changes in gene transcription. Review Figures 15.14, 15.15 Direct Intercellular Communication Most animal cells can communicate with one another directly through small pores in their plasma membranes called gap junctions. Small molecules and ions can pass through these pores. Review Figure 15.16 Plant cells are connected by somewhat larger pores called plasmodesmata, which traverse both membranes and cell walls. Review Figure 15.17. See Web/CD Activity 15.2 for a concept review of this chapter. CHAPTER 16: RECOMBINANT DNA AND BIOTECHNOOGY Cleaving and Rejoining DNA Knowledge of DNA transcription, translation, and replication has been used to create recombinant DNA molecules, made up of sequences from different organisms. Restriction enzymes, which are made by bacteria as a defense against viruses, bind to DNA at specific recognition sequences and cut it. Review Figure 16.1 DNA fragments generated from cleavage by restriction enzymes can be separated by size using gel electrophoresis. The sequences of these fragments can be further identified by hybridization with a probe. Review Figures 16.2, 16.3. See Web/CD Tutorial 16.1 Many restriction enzymes make staggered cuts in the two strands of DNA, creating "sticky ends" with unpaired bases. These sticky ends can be used to create recombinant DNA if DNA molecules from different species are cut with the same restriction enzyme. Review Figure 16.4 Getting New Genes into Cells Bacteria, yeasts, and cultured plant cells are commonly used as hosts for recombinant DNA procedures. Newly introduced DNA must be part of a replication unit if it is to be propagated in host cells. One way to make sure that the transfected DNA is part of such a unit is to insert it into a vector. There are specialized vectors for transfecting bacteria, yeasts, and plant cells. These vectors must contain an origin of replication, recognition sequences for restriction enzymes, and reporter genes to identify their presence in host cells. Review Figure 16.5 Reporter genes conferring nutritional, antibiotic resistance, or fluorescent phenotypes can be used to identify which host cells have taken up the recombinant vector. Review Figure 16.6 Sources of Genes for Cloning The cutting of DNA by a restriction enzyme produces many fragments that can be individually and randomly combined with a vector and inserted into a host to create a gene library. Review Figure 16.7 The mRNAs produced in a certain tissue at a certain time can be extracted and used to create complementary DNA (cDNA) by reverse transcription. Review Figure 16.8 A third source of DNA is synthetic DNA made by chemists in the laboratory. The methods of organic chemistry can be used to create or mutate DNA sequences. Some Additional Tools for DNA Manipulation Homologous recombination can be used to "knock out" a gene in an organism. Review Figure 16.9 DNA chip technology permits the screening of thousands of

sequences at the same time. Review Figure 16.10. See Web/CD Tutorial 16.2 An antisense or interfering RNA complementary to a specific mRNA can prevent translation of the mRNA by hybridizing with it. Review Figure 16.11 A two-hybrid system allows scientists to determine which proteins interact in cells. Review Figure 16.12 Biotechnology: Applications of DNA Manipulation Recombinant DNA techniques have made possible many new applications of biotechnology, such as the large-scale production of eukaryotic gene products. Expression vectors carry sequences such as promoters and transcription terminators that allow a gene of interest to be expressed in a host cell. Review Figure 16.13. See Web/CD Activity 16.1 Recombinant DNA techniques have been used to make medically useful proteins that would otherwise have been difficult to obtain in necessary quantities. Review Figure 16.14, Table 16.1 Because recombinant DNA technology has several advantages over traditional agricultural biotechnology, it is being extensively applied to agriculture. Review Table 16.2 Because plant cells can be cloned to produce adult plants, the introduction of new genes into crop plants has been advancing rapidly. Transgenic crop plants can be adapted to their environment, instead of vice versa. "Pharming" uses transgenic animals that produce useful products in their milk. There is public concern about the application of recombinant DNA technology to food production. Because the DNA of an individual is unique, the polymerase chain reaction can be used to identify an organism from a small sample of its cells-that is, to create a DNA fingerprint. Review Figures 16.17, 16.18

CHAPTER 17: MOLECULAR BIOLOGY AND MEDICINE Abnormal or Missing Proteins: The Mutant Phenotype In some human genetic diseases, a single protein is missing or nonfunctional. Review Figure 17.1 A mutation in a single gene can cause alterations in its protein product that may lead to clinical abnormalities or have no effect. Review Figure 17.2 The genes that code for enzymes, membrane receptors, and membrane transport proteins can be mutated, causing diseases such as phenylketonuria, familial hypercholesterolemia, and cystic fibrosis. Review Figure 17.3 Some diseases are caused by mutations that affect structural proteins; examples include Duchenne muscular dystrophy and hemophilia. Prions are disease-causing proteins with an altered conformation that can be transmitted from one person to another and alter the same protein in the second person. Review Figure 17.4 Relatively few common human diseases are caused by single-gene mutations. Most are caused by the interactions of many genes and proteins with the environment. Human genetic diseases show different patterns of inheritance. Mutant alleles may be inherited as autosomal recessives, autosomal dominants, or X-linked conditions. Some human diseases are caused by chromosomal abnormalities. Mutations and Human Diseases Molecular biological techniques have made possible the isolation of many genes responsible for human diseases. One method of identifying the gene responsible for a disease is to isolate the mRNA for the abnormal protein in question and then use that mRNA to locate the gene in a gene library. DNA from a patient with a chromosome deletion can be compared with DNA from a person who does not show this deletion to isolate a missing gene. Review Figure 17.6 In positional cloning, genetic markers are used as guides to point the way to a gene. These markers may

be restriction fragment length polymorphisms that are linked to a mutant gene. Review Figure 17.7. See Web/CD Activity 17.1 Human mutations range from point mutations to large deletions. Some of the most common mutations occur where the modified base 5-methylcytosine is converted to thymine. Review Figure 17.8 The effects of the fragile-X chromosome worsen with each generation. This pattern is caused by a triplet repeat that tends to expand with each new generation. Review Figure 17.9 Genomic imprinting results in a gene being differentially expressed depending on the sex of the parent it comes from. Detecting Genetic Variations: Screening for Human Diseases Genetic screening detects human genetic mutations. Some protein abnormalities can be detected by simple tests, such as tests for the presence of excess substrate or lack of product. Review Figure 17.10 The advantage of testing DNA for mutations directly is that any cell can be tested at any time in the life cycle. There are two predominant methods of DNA testing: allele-specific cleavage and allele-specific oligonucleotide hybridization. Review Figures 17.11, 17.12. See Web/CD Tutorial 17.1 Cancer: A Disease of Genetic Changes Tumors may be benign, growing only to a certain extent and then stopping, or malignant, spreading through organs and to other parts of the body. At least five types of human cancers are caused by viruses, which account for about 15 percent of all cancers. Review Table 17.1 Eighty-five percent of human cancers are caused by genetic mutations of somatic cells. These mutations occur most commonly in dividing cells. Review Figure 17.14 Normal cells contain oncogenes, which, when mutated, can become activated and cause cancer by stimulating cell division or preventing cell death. Review Figure 17.15 About 10 percent of all cancer is inherited as a mutation of a tumor suppressor gene, which normally acts to slow down the cell cycle. For cancer to develop, both alleles of a tumor suppressor gene must be mutated. In inherited cancer, an individual inherits one mutant allele of a tumor suppressor gene, and a somatic mutation occurs in the second one. In sporadic cancer, two normal alleles are inherited, so two mutational events must occur in the same somatic cell to produce cancer. Review Figures 17.16, 17.17 Mutations must activate several oncogenes and inactivate several tumor suppressor genes for a cell to produce a malignant tumor. Review Figure 17.18 Treating Genetic Diseases Most genetic diseases are treated symptomatically. However, as more knowledge is accumulated, specific treatments are being devised. One approach to treating genetic diseases is to modify the phenotype—for example, by manipulating the diet to restrict the substrate of a missing enzyme, providing specific metabolic inhibitors to prevent a harmful reaction, or supplying a missing metabolite or protein. Review Figure 17.19 In gene therapy, a mutant gene is replaced with a normal gene. The affected cells can be removed, the new gene added, and the cells returned to the body, or the new gene can be inserted via a vector directly into the patient. Review Figure 17.20 Sequencing the Human Genome Sequencing the entire human genome required sequencing many 500-base-pair fragments and then fitting their sequences back together. In hierarchical gene sequencing, marker sequences are identified and mapped on the chromosome before DNA is fragmented. These markers are then sought in the sequenced fragments and used to align them. In the shotgun approach, the DNA is fragmented and sequenced, and common markers are then identified by computer. Review Figure 17.21. See Web/CD Tutorial 17.2 The human genome has only about 21,000 genes. Review Figure 17.22 The identification of human genes may lead to a new

molecular medicine. Review Figure 17.23 As more genes relevant to human health are described, concerns about how such information is used are growing. Humans make many more proteins than predicted by their number of genes because each gene can encode several different proteins as a result of variation in posttranscriptional and posttranslational regulation. Thus, the proteome is more complex than the genome. Review Figure 17.24 CHAPTER 18: NATURAL DEFENSES AGAINST DISEASE Animal Defense Systems Animals defend themselves against pathogens by both nonspecific (innate) and specific means. Defensive Cells and Proteins Many of our defenses are implemented by cells and proteins carried in the bloodstream and in the lymphatic system. Review Figure 18.1. See Web/CD Activity 18.1 White blood cells, including lymphocytes (B and T cells) and phagocytes (such as neutrophils and macrophages), play many defensive roles. Review Figure 18.2. See Web/CD Tutorial 18.1 Nonspecific Defenses An animal's nonspecific defenses include physical barriers, competing resident microorganisms, and local agents, such as secretions that contain an antibacterial enzyme. Review Table 18.1 The inflammation response uses several cells and proteins. Activated mast cells release histamine, which causes blood capillaries to leak and inflame. Complement proteins attract macrophages to the site, where they engulf bacteria and dead cells. Review Figure 18.4. See Web/CD Activity 18.2 A cell signaling pathway involved the toll receptor stimulates the defense response. Review Figure 18.5 Specific Defenses: The Immune Response Four features characterize the immune response: specificity, the ability to respond to an enormous diversity of antigens, the ability to distinguish self from nonself, and memory. The immune response is directed against antigens that evade the nonspecific defenses. Each antibody or T cell is directed against a particular antigenic determinant. Review Figure 18.6 There are two interactive immune responses: the humoral immune response and the cellular immune response. The humoral immune response employs antibodies secreted by B cells to target antigens in body fluids. The cellular immune response employs T cells to attack body cells that have been altered by viral infection or mutation or to target antigens that have invaded the body's cells. Clonal selection accounts for the rapidity, specificity, and diversity of the immune response as well as immunological memory and tolerance to self. Review Figure 18.7 Immunological memory plays roles in both natural immunity and artificial immunity based on vaccination. Review Figure 18.8, Table 18.2 B Cells: The Humoral Immune Response Activated B cells form plasma cells, which synthesize and secrete specific antibodies. The basic unit of an antibody, or immunoglobulin, is a tetramer of four polypeptides: two identical light chains and two identical heavy chains, each consisting of a constant and a variable region. Review Figure 18.10. See Web/CD Activity 18.3 The variable regions of the light and heavy chains collaborate to form the antigen-binding sites of a specific antibody. Each antigen usually has several different antigenic determinants (binding sites for specific antibodies). The variable regions determine each antibody's specificity for a determinant; the constant region determines the destination and function of the antibody. There are five immunoglobulin classes. IgM, formed first, is a membrane receptor on B cells, as is IgD. IgG is the most abundant antibody class and performs several defensive functions. IgE takes part in inflammation and allergic reactions. IgA is present in various body secretions. Review Table 18.3 Monoclonal antibodies consist of identical immunoglobulin molecules

directed against a single antigenic determinant. Review Figure 18.12 See Web/CD Tutorial 18.2 T Cells: The Cellular Immune Response The cellular immune response is directed against altered or infected cells of the body. TC cells attack virus-infected or tumor cells, causing them to lyse. TH cells activate B cells and influence the development of other T cells and macrophages. Review Figure 18.13 T cell receptors in the cellular immune response are analogous to immunoglobulins in the humoral immune response. The major histocompatibility complex (MHC) encodes many membrane proteins. MHC molecules in macrophages, B cells, or body cells bind processed antigen and present it to T cells. Review Figures 18.15, 18.16 In the cellular immune response, class I MHC molecules, TC cells, CD8, and cytokines collaborate to activate TC cells with the appropriate specificity. Review Figure 18.17. See Web/CD Tutorial 18.4 Developing T cells undergo two tests: They must be able to recognize self MHC molecules, and they must not bind to both self MHC and any of the body's own antigens. T cells that fail either of these tests die. The rejection of organ transplants results from the genetic diversity of MHC molecules. See Web/CD Tutorial 18.3 The Genetic Basis of Antibody Diversity Immunoglobulin heavy-chain supergenes are constructed from one each of numerous V, D, J, and C segments. The V, D, and J segments combine by DNA rearrangement, and transcription yields an RNA molecule that is spliced to form a translatable mRNA. Other gene families give rise to the light chains. Review Figures 18.18, 18.19 As a result of these DNA rearrangements, there are millions of possible antibodies as a result of these DNA combinations. Imprecise DNA rearrangements, mutations, and random addition of bases to the ends of the DNAs before they are joined contribute even more diversity. Class switching after initial immunoglobulin production results in antibodies with the same antigen specificity but a different function. It is accomplished by cutting and rejoining of the genes encoding the constant region. Review Figure 18.20. See Web/CD Tutorial 18.5 Disorders of the Immune System Allergies result from an overreaction of the immune system to an antigen. Autoimmune diseases result from a failure in the immune recognition of self, with the appearance of antiself B and T cells that attack the body's own cells. Immune deficiency disorders result from failures of one or another part of the immune system. AIDS is an immune deficiency disorder arising from depletion of the body's TH cells as a result of infection with HIV. Depletion of the TH cells weakens and eventually destroys the immune system, leaving the host defenseless against "opportunistic" infections. Review Figures 18.21, 18.22 HIV inserts a copy of its genome into a chromosome of a macrophage or TH cell, where it may lie dormant for years. When the viral genome is transcribed and translated, new viruses form. Currently the most effective drugs to treat HIV are those directed against reverse transcriptase and protease. Some treatments may provide a dramatic reduction in HIV levels, but there is as yet no indication that we can prevent infection with HIV, as by vaccination. The only strategy currently available is for people to avoid behaviors that place them at risk. CHAPTER 19: DIFFERENTIAL GENE EXPRESSION IN DEVELOPMENT The Processes of Development A multicellular organism develops through a series of embryonic stages and eventually into an adult. Development continues until death. Review Figure 19.1 Growth results from a combination of cell division and cell expansion. Differentiation produces specialized cell types. Morphogenesis—the creation of the overall form of the multicellular organism—is the result of pattern formation. In many

organisms, the fates of early embryonic cells have not yet been determined. These cells may develop into different tissues if transplanted to a different part of an embryo. Review Figure 19.2 As the embryo develops, its cells gradually become determined—committed to developing into particular cell types. Following determination, cells eventually differentiate into their final, often specialized, forms. The Role of Differential Gene Expression in Cell Differentiation The zygote is totipotent; it contains the entire genetic constitution of the organism and is capable of forming all adult tissues. Two lines of evidence show that differentiation does not involve permanent changes in the genome. First, nuclear transplantation and cell fusion experiments show that the nucleus of a differentiated cell retains the ability to act like a zygote nucleus and direct the production of an entire organism. Second, molecular investigations have shown directly that all cells contain all genes for the organism, but that only certain genes are expressed in a given tissue. Review Figures 19.3, 19.4, 19.5 Embryonic stem cells are totipotent, and they can be cultured in the laboratory. With suitable environmental stimulation, these cells can be induced to form cells that differentiate into a particular type. Review Figure 19.6 The Role of Cytoplasmic Segregation and Induction in Cell Determination Unequal distribution of cytoplasmic determinants in the egg, zygote, or embryo can lead to cell determination. Experimentally altering this distribution can alter gene expression and produce abnormal or nonfunctional organisms. Review Figures 19.7, 19.8. See Web/CD Tutorial 19.1 Some embryonic animal tissues direct the development of their neighbors by secreting inducers. Induction is often reciprocal: One tissue induces a neighbor to change, and the neighbor, in turn, induces the first tissue to change, as in eye formation in vertebrate embryos. Review Figure 19.9 Induction in the nematode Caenorhabditis elegans can be very precise, with individual cells producing specific effects in just two or three neighboring cells. Review Figure 19.10 The Role of Pattern Formation in Organ Development Apoptosis is important in pattern formation. Some genes whose protein products regulate apoptosis have been identified. Review Figure 19.11 Plants have organ identity genes that interact to cause the formation of sepals, petals, stamens, and carpels. Mutations of these genes may cause meristem cells to form a different organ. Review Figure 19.12 Plant organ identity genes code for transcription factors of the MADS box family. Both plants and animals use positional information as a basis for pattern formation. Gradients of morphogens provide this information. The Role of Differential Gene Expression in Establishing Body Segmentation The fruit fly Drosophila melanogaster has provided much information about the development of body segmentation. The first genes to act in determining Drosophila segmentation are maternal effect genes, such as bicoid and nanos, which encode morphogens that form gradients in the egg. These morphogens act on segmentation genes to define the anterior-posterior organization of the embryo. Review Figure 19.14 There are three kinds of segmentation genes. Gap genes organize broad areas along the anterior-posterior axis, pair rule genes divide the axis into pairs of segments, and segment polarity genes define the anterior-posterior axis of each segment. Review Figure 19.15. See Web/CD Tutorial 19.2 Segmentation develops as the result of a transcriptionally controlled cascade, with the product of each gene promoting or repressing the expression of the next. Activation of the segmentation genes leads to the activation of the appropriate homeotic

genes in each segment. The homeotic genes define the functional characteristics of the segments. Mutations of homeotic genes often have bizarre effects, causing structures to form in inappropriate parts of the body. Homeotic genes contain a sequence called the homeobox, which encodes the homeodomain, an amino acid sequence that is part of many transcription factors. CHAPTER 20: ANIMAL DEVELOPMENT: FROM GENES TO ORGANISM Development Begins with Fertilization The sperm and the egg contribute differentially to the zygote. The sperm contributes a haploid nucleus and, in some species, a centriole. The egg contributes a haploid nucleus, nutrients, ribosomes, mitochondria, and mRNAs. The cytoplasmic contents of the egg are not distributed homogeneously, and they are rearranged after fertilization to set up the major axes of the future embryo. Review Figures 20.2, 20.3 Cleavage: Repackaging the Cytoplasm In most animals, cleavage is a period of rapid cell division without cell expansion or gene expression. During cleavage, the cytoplasm of the zygote is repackaged into smaller and smaller cells. The pattern of cleavage is influenced by the amount of yolk, which impedes cleavage furrow formation, and by the orientation of the mitotic spindles. The result of cleavage is a ball or mass of cells called a blastula. Review Figure 20.4 Cleavage in mammals is unique in that cell divisions are very slow and genes are expressed early in the process. Cleavage results in an inner cell mass that becomes the embryo and an outer cell mass that becomes the trophoblast. The mammalian embryo at this stage is called a blastocyst. Review Figure 20.5 A fate map can be created by labeling specific blastomeres and observing what tissues and organs are formed by their progeny. Review Figure 20.6 Some species undergo mosaic development, in which the fate of each cell is determined by the 8-cell stage. Other species, including vertebrates, undergo regulative development, in which remaining cells can compensate for cells lost in early cleavages. Gastrulation: Producing the Body Plan Gastrulation involves massive cell movements that produce three germ layers and place cells from various regions of the blastula into new associations with one another. The initial step of sea urchin and amphibian gastrulation is inward movement of certain blastomeres. The site of inward movement becomes the blastopore. Cells that move into the blastula become the endoderm and mesoderm; cells remaining on the outside become the ectoderm. Cytoplasmic factors in the vegetal pole cells are essential to initiate development. Review Figures 20.8, 20.9 Amphibian gastrulation is initiated when cells in the gray crescent move into the blastocoel. This inward migration creates the blastopore. The dorsal lip of the blastopore is a critical site for cell determination. It has been called the primary embryonic organizer. Review Figures 20.9, 20.10, 20.11. See Web/CD Tutorials 20.1 and 20.2 The protein β-catenin activates a signaling cascade that induces the primary embryonic organizer and sets up the anterior-posterior body axis. Review Figure 20.12 Left-right asymmetries are probably controlled by the asymmetrical distribution of early transcription factors during gastrulation. Gastrulation in reptiles and birds differs from that in sea urchins and frogs because the large amount of yolk in their eggs causes the blastula to form a flattened disc of cells. Review Figure 20.13 Mammals have a pattern of gastrulation similar to that of birds, even though their eggs have no yolk. Neurulation: Initiating the Nervous System Gastrulation is followed by organogenesis. Cells that migrate over the dorsal lip of the blastopore are determined to become the notochord. The notochord induces the overlying ectoderm to

thicken, form parallel ridges, and fold in on itself to form a neural tube below the epidermal ectoderm. The nervous system develops from this neural tube. Review Figure 20.15 The notochord and neural crest cells participate in the segmental organization of tissues called somites along the body axis. Rudimentary organs and organ systems form during these stages. Review Figure 20.16 Four families of Hox genes determine the pattern of anterior-posterior differentiation along the body axis in mammals. Other genes, such as sonic hedgehog, contribute to dorsal-ventral differentiation. Review Figure 20.17 Extraembryonic Membranes The embryos of reptiles, birds, and mammals are protected and nurtured by four extraembryonic membranes. In birds and reptiles, the yolk sac surrounds the yolk and provides nutrients to the embryo, the chorion lines the eggshell and participates in gas exchange, the amnion surrounds the embryo and encloses it in an aqueous environment, and the allantois stores metabolic wastes. Review Figure 20.18. See Web/CD Activity 20.1 In mammals, the chorion and the trophoblast cells interact with the maternal uterus to form a placenta, which provides the embryo with nutrients and gas exchange. The amnion encloses the embryo in an aqueous environment. Review Figure 20.14, 20.19 Samples of amniotic fluid or pieces of the chorion can be analyzed for evidence of genetic disease. Review Figure 20.20 Human Development Pregnancy in humans can be divided into three trimesters. The embryo forms in the first trimester; during this time, it is most vulnerable to environmental factors that can lead to birth defects. During the second and third trimesters the embryo grows, the limbs elongate, and the organ systems mature. Hormonal changes maintain the pregnancy and also cause symptoms of pregnancy in the mother. Development continues throughout childhood and throughout life.

CHAPTER 21: DEVELOPMENT AND EVOLUTIONARY CHANGE Evolution and Development The field of evolutionary developmental biology unites embryology, ecology, and genetics. It is generating new information that helps us understand how the recipes for making organisms interact with environmental signals to produce functional organisms. Relationships among organisms can often be inferred by similarities in their embryonic or larval features. Many of the genes regulating development have changed very little throughout animal evolution. The same sets of genes are involved in specifying the anterior-posterior axis in both vertebrates and invertebrates. Review Figure 21.3 Regulatory Genes and Modularity: Modifying Morphology Major morphological changes can result from mutations in developmental regulatory genes or from alterations in the time or place of expression of these genes. Review Figures 21.5, 21.6. See Web/CD Tutorial 21.1 Modularity allows morphological changes to occur without disrupting the entire organism. Heterochrony, a shift in the relative timing of two different developmental processes, can result in new morphology. Review Figure 21.8 Plant Development and Evolution Plants differ from animals in important ways that influence how they develop. Plant cells do not move relative to one another during development. In addition, the reproductive cells are not set aside early during plant development. Instead, plants continue to produce undifferentiated meristems as long as they grow. And plants have great developmental

plasticity. See Web/CD Activity 21.1 Despite these differences, plants have MADS box genes and homeobox genes, some of which are shared with animals, although they govern the development of structures unique to plants. Environmental Influences on Developmental Patterns A genotype may encode a range of phenotypes. Developmental plasticity is the ability to express different phenotypes under different environmental conditions. Some environmental signals always occur and accurately predict future conditions. Others may or may not occur, but are good predictors of future conditions when they do appear. The development of organisms often responds adaptively to such signals. Review Figure 21.9 Many organisms have the ability to detect the presence of predators and alter their development to reduce the likelihood that they will be attacked. Organisms evolve to not respond to environmental signals that are poor predictors of future conditions. Plants respond to light and other environmental conditions by changing their shapes and the number of flowers or seeds they produce, but not the sizes of their seeds. Review Figure 21.13 Knowledge of how developing organisms are influenced by chemical agents that disrupt normal development may help us find alternative materials to use that are less damaging. Learning: A Modification of Development Learning is a costly way of modifying development, but it can continue throughout adult life, and it allows an individual to adjust its behavior to the environment in which it matures. CHAPTER 22: THE HISTORY OF LIFE ON EARTH Defining Biological Evolution Biology is intimately linked to concepts of time. The study of biology as we know it could not have been developed until people came to understand the age of Earth. Determining Earth's Age The relative ages of rock layers in Earth's crust were determined from their embedded fossils. Radioisotopes supplied the key for assigning absolute ages to rocks. Earth's geological history is divided into eras and periods. The boundaries between these divisions are based on differences between their fossil biotas. Review Table 22.1 The Changing Face of Earth Throughout Earth's history continents have drifted about, sometimes separating from one another, at other times colliding. Their collisions typically have led to periods of massive volcanic eruptions, glaciations, and major shifts in sea levels and ocean currents. Review Figure 22.2 Earth's early atmosphere lacked free oxygen. Oxygen accumulated after prokaryotes evolved the ability to use water as their source of hydrogen ions for photosynthesis. Increasing concentrations of atmospheric oxygen made possible the evolution of eukaryotes and multicellular organisms. Review Figure 22.4 Over Earth's history, hot/humid climatic conditions have alternated with cold/dry conditions. Review Figure 22.5 External events, such as collisions with meteorites, also have changed conditions on Earth. Such a collision probably caused the abrupt mass extinction at the end of the Cretaceous period. See Web/CD Tutorial 22.1 The Fossil Record Much of what we know about the history of life on Earth comes from the study of fossils. The fossil record, although incomplete, reveals broad patterns in the evolution of life. About 300,000 fossil species have been described. The best record is that of hard-shelled animals fossilized in marine sediments. Major Patterns in the History of Life on Earth Some lineages that evolved during Precambrian times may not have left living descendants. The diversity of life exploded during the Cambrian period. Diversification continued throughout the rest of the Paleozoic era. Review Figures 22.9, 22.11, 22.13 Geographic differentiation of biotas increased during the Mesozoic era. Review Figure 22.16 The modern biota

evolved during the Cenozoic era. After each mass extinction, the diversity of life rebounded, but the groups of organisms that dominated the new biotas differed markedly from those characteristic of earlier biotas. Review Figure 22.17 Rates of Evolutionary Change within Lineages Some species, called "living fossils," closely resemble ancient ancestors. Evolutionary changes have been gradual in some lineages. Review Figure 22.19 Rates of evolutionary change are sometimes rapid because of changes in the physical or biological environment. Review Figures 22.20, 22.21. See Web/CD Activity 22.1 for a concept review of this chapter. The Future of Evolution The agents of evolution continue to operate today, but human intervention, both deliberate and inadvertent, now plays an unprecedented role in the history of life. CHAPTER 23: THE MECHANISMS OF EVOLUTION Charles Darwin's Theory of Evolution Darwin developed his theory of evolution by natural selection by carefully observing nature, especially during his voyage around the world on the Beagle. Review Figure 23.1 Darwin based this theory on well-known facts and some key inferences. Modern genetics has discovered the mechanisms of inheritance, which Darwin did not understand. Darwin had no examples of the action of natural selection, so he based his arguments on artificial selection. See Web/CD Tutorial 23.1 Genetic Variation within Populations For a population to evolve, its members must possess heritable genetic variation, which is the raw material on which agents of evolution act. A single individual has only some of the alleles found in the population of which it is a member. Review Figure 23.3 Considerable genetic variation characterizes most natural populations. Review Figures 23.4, 23.5 Allele frequencies measure the amount of genetic variation in a population. Biologists estimate allele frequencies by measuring a sample of individuals from a population. The sum of all allele frequencies at a locus is equal to 1. Review Figure 23.6 Genotype frequencies show how a population's genetic variation is distributed among its members. Populations that have the same allele frequencies may nonetheless have different genotype frequencies. The Hardy-Weinberg Equilibrium Several conditions are required for a population to be at Hardy-Weinberg equilibrium: mating is random, the population is very large, there is no migration, there is no mutation, and natural selection is not acting on the population. In a population at Hardy-Weinberg equilibrium, allele frequencies remain the same from generation to generation. In addition, genotype frequencies will remain in the proportions $p^2 + 2pq + q^2 = 1$. Review Figure 23.7 Biologists can determine whether an agent of evolution is acting on a population by comparing the genotype frequencies of that population with Hardy-Weinberg expectations. See Web/CD Tutorial 23.2 Evolutionary Agents and Their Effects Changes in the genetic structure of populations are caused by several evolutionary agents: mutation, gene flow, genetic drift, nonrandom mating, and natural selection. The origin of genetic variation is mutation. Most mutations are harmful or neutral to their bearers, but some are advantageous, particularly if the environment changes. Movement of individuals or gametes from one population to another, followed by reproduction in the new location, produces gene flow. Gene flow may add new alleles to a population or may change the frequencies of alleles already present. The random loss of alleles, known as genetic drift, produces changes in allele frequencies, which may be especially dramatic in small populations. Organisms that normally have large populations may pass through occasional periods (bottlenecks) when only a small number of individuals survive. Review

Figure 23.8 New populations established by a few founding immigrants also have gene frequencies that differ from those in the parent population. Review Figure 23.10 If individuals mate more often with other individuals of a certain genotype than would be expected on a random basis—that is, when mating is not random—genotype frequencies differ from Hardy-Weinberg expectations. Review Figure 23.11 Self-fertilization, an extreme form of nonrandom mating, reduces the frequencies of heterozygous individuals below Hardy-Weinberg expectations without changing allele frequencies. Natural selection is the only agent of evolution that adapts populations to their environments. The reproductive contribution of a phenotype to subsequent generations relative to the contributions of other phenotypes is its fitness. The fitness of a phenotype is determined by the average rates of survival and reproduction of individuals with that phenotype. The Results of Natural Selection Stabilizing selection reduces variation and preserves the average characteristics of a population. Review Figures 23.12a, 23.13 Directional selection changes a character by favoring individuals that vary in one direction from the population mean. If directional selection operates over many generations, an evolutionary trend may result. Review Figures 23.12b, 23.14 Disruptive selection changes a character by favoring individuals that vary in both directions from the population mean. Review Figures 23.12c, 23.15 Sexually selected traits may evolve because females prefer to mate with males having those traits. Review Figures 23.16, 23.17 Assessing the Costs of Adaptations Possessing resistance to toxic chemicals may involve trade-offs, such as reduced reproductive output. Review Figure 23.18. See Web/CD Tutorial 23.3 Sexually selected traits may result in higher parasite loads and mortality rates in males. Review Figure 23.19 Maintaining Genetic Variation Genetic drift, stabilizing selection, and directional selection all tend to reduce genetic variation, but most populations are genetically highly variable. Sexual recombination increases the evolutionary potential of populations, but it does not influence the frequencies of alleles. Rather, it generates new combinations of genetic material on which natural selection can act. Genetic variation within a population may be maintained by frequency-dependent selection. Review Figure 23.20 Much genetic variation is maintained geographically. Review Figure 23.21 Constraints on Evolution Natural selection acts by modifying what already exists. Cultural Evolution Learned traits can spread rapidly via cultural evolution. Short-Term versus Long-Term Evolution Patterns of long-term evolutionary change can be strongly influenced by events that occur so infrequently or so slowly that they are unlikely to be observed during short-term evolutionary studies. Additional types of evidence must be gathered to understand why evolution in the long term took the particular course it did. CHAPTER 24: SPECIES AND THEIR FORMATION What Are Species Species are independent evolutionary units. A commonly accepted definition of species is "groups of actually or potentially interbreeding natural populations which are reproductively isolated from other such groups." Because speciation is often a gradual process, it may be difficult to recognize boundaries between species. Review Figure 24.3 How Do New Species Arise? Not all evolutionary changes result in new species. Allopatric (geographic) speciation is the most important mode of speciation among animals and is common in other groups of organisms. Review Figures 24.4, 24.5, 24.6. See Web/CD Tutorial 24.2 Sympatric speciation may occur rapidly by polyploidy because polyploid offspring are sterile in crosses with members of the parent species. Polyploidy is

a major factor in plant speciation but is rare among animals. Review Figures 24.7, 24.8. See Web/CD Tutorial 24.1 Completing Speciation: Reproductive Isolating Mechanisms Once two populations have been separated, reproductive isolating mechanisms may prevent the exchange of genes between them. Prezygotic reproductive barriers operate before fertilization. Some prezygotic barriers affect mate choice; others work by influencing pollinator behavior. Review Figures 24.10, 24.11 Postzygotic reproductive barriers operate after fertilization by reducing the survival or fertility of hybrid offspring. If hybrid offspring survive poorly, more effective prezygotic reproductive barriers may evolve. This process is known as reinforcement. Review Figure 24.12 Hybrid Zones: Incomplete Reproductive Isolation Hybrid zones may develop if barriers to gene exchange fail to develop while diverging species are isolated from each other. Review Figure 24.13 Species may differ from one another in very few genes. Variation in Speciation Rates Rates of speciation differ greatly among lineages. Speciation rates are influenced by the number of species in a lineage, their dispersal rates, ecological specialization, experience of population bottlenecks, pollinators, and behavior, as well as by climatic changes. Evolutionary Radiations Evolutionary radiations occur when speciation rates exceed extinction rates. High speciation rates often coincide with low extinction rates when species invade islands or other environments that contain few other species. As a result of speciation, Earth is populated with millions of species, each adapted to live in a particular environment and to use resources in a particular way. See Web/CD Activity 24.1 for a concept review of this chapter.

CHAPTER 25: RECONSTRUCTING AND USING PHYLOGENIES Systematics is the scientific study of the diversity of organisms. Taxonomy, a subdivision of systematics, is the theory and method of classifying organisms. Phylogenetic Trees A phylogenetic tree displays the order in which lineages split. Review Figure 25.1 Traits inherited from a common ancestor, called ancestral traits, are said to be homologous. A derived trait is one that differs from its form in the ancestor of a lineage. Traits that are similar as a result of convergent evolution or evolutionary reversals are said to be homoplastic. Review Figure 25.2 Steps in Reconstructing Phylogenies Systematists use morphological, physiological, behavioral, and molecular characters to reconstruct phylogenies. Structures in early developmental stages sometimes show evolutionary relationships that are not evident in adults. Review Figure 25.4 Protein primary structures and the base sequences of nucleic acids are also important traits that can be used in reconstructing phylogenies. Reconstructing a Simple Phylogeny To assess evolutionary relationships, systematists must distinguish between ancestral and derived traits within a lineage. This task is often difficult because traits can change more than once or undergo evolutionary reversal. Review Figure 25.5 Systematists use the parsimony principle to reconstruct phylogenetic trees. See Web/CD Activity 25.1 Biological Classification and Evolutionary Relationships Classification systems improve our ability to explain relationships among things, aid our memory, and provide unique, universally used names for organisms. Biological nomenclature assigns to

each organism a unique combination of a generic and a specific name. In the universally employed Linnaean classification system, species are grouped into higher-level units called genera, families, orders, classes, phyla, and (in some cases) kingdoms. Review Figure 25.6 Taxonomists agree that taxa should be monophyletic and that polyphyletic groups should not be recognized. Review Figure 25.7. See Web/CD Activity 25.2 Paraphyletic taxa may be retained because of their familiarity and to highlight the fact that members of some lineages evolved unique traits. Review Figure 25.8 Phylogenetic Trees Have Many Uses Phylogenetic trees help biologists to determine how many times evolutionary traits have arisen, explain the geographic ranges of species, and date evolutionary radiations. Review Figures 25.9, 25.10, 25.11 CHAPTER 26: MOLECULAR AND GENOMIC EVOLUTION Genomes and Their Evolution A genome is the full set of genes an organism contains. The genes in an organism's genome are usefully viewed as interacting members of a group. The Evolution of Macromolecules Molecular evolutionists characterize the structures of macromolecules and use them to determine how rapidly these macromolecules have changed and why they have changed. Mutations and genetic drift are important determinants of rates of molecular evolution. Review Figure 26.1 Determining and Comparing the Structure of Macromolecules Molecules are compared by aligning their sequences and counting the differences between those sequences. Review Figure 26.2. See Web/CD Activity 26.2 Changes evolve slowly in regions of molecules that are functionally significant, but more rapidly in regions where substitutions do not affect the functioning of the molecules. Review Figures 26.3, 26.4 Rates of substitution in some molecules are relatively constant over evolutionary time; that is, these molecules can serve as molecular clocks. Review Figure 26.5. See Web/CD Activity 26.1 Proteins Acquire New Functions Most new protein functions arise by gene duplication. Changes in the functions performed by proteins may also result from changes in the physiological roles of gene products. The Evolution of Genome Size The genome sizes of organisms vary tremendously, but the amount of DNA that actually encodes RNAs or proteins varies much less. Review Figures 26.7, 26.8 Complex organisms have more coding DNA than simpler ones. The globin family of proteins evolved via gene duplication. Review Figure 26.9 The Uses of Molecular and Genomic Information Molecular data can be used to infer phylogenetic relationships among organisms. Molecules that have evolved slowly are useful for determining ancient lineage splits. Molecules that have evolved rapidly are useful for determining more recent lineage splits in combination with morphological and fossil data. Molecular data are used to determine the phylogenetic histories of genes. Review Figure 26.10 Molecular data are used to find new ways to combat diseases. See Web/CD Activity 26.3 CHAPTER 27: BACTERIA AND ARCHAEA: THE PROKARYOTIC DOMAINS Why Three Domains? Living organisms can be divided into three domains: Bacteria, Archaea, and Eukarya. Both the Archaea and the Bacteria are prokaryotic; the Eukarya constitute the rest of the living world. The Bacteria and the Archaea are less closely related to each other than are the Archaea and the Eukarya. Review Figure 27.2, Table 27.1 The common ancestor of all three domains lived more than 3 billion years ago, and the common ancestor of the Archaea and Eukarya at least 2 billion years ago. See Web/CD Tutorial 27.1 General Biology of the Prokaryotes The prokaryotes are the most numerous organisms on Earth, and they occupy an enormous variety of habitats. Most prokaryotes are cocci, bacilli, or spiral forms. Some link together to form associations, but very few are

truly multicellular. Review Figure 27.3 Prokaryotes lack nuclei, membrane-enclosed organelles, and cytoskeletons. Their chromosomes are circular. They often contain plasmids. Some prokaryotes contain internal membrane systems. Many prokaryotes move by means of flagella, gas vesicles, or gliding mechanisms. Prokaryotic flagella rotate rather than beat. Review Figures 27.4, 27.5 Prokaryotic cell walls differ from those of eukaryotes. Bacterial cell walls generally contain peptidoglycan. Differences in peptidoglycan content result in different reactions to the Gram stain. Review Figure 27.6. See Web/CD Activity 27.1 Prokaryotes reproduce asexually by fission, but also exchange genetic information. Prokaryotes have diverse metabolic pathways and nutritional modes. They include obligate anaerobes, facultative anaerobes, and obligate aerobes. The major nutritional types are photoautotrophs, photoheterotrophs, chemolithotrophs, and chemoheterotrophs. Some prokaryotes base their energy metabolism on nitrogen- or sulfur-containing ions. Review Figure 27.7 and Table 27.2 Prokaryotes in Their Environments Some prokaryotes play key roles in global nitrogen and sulfur cycles. Important players in the nitrogen cycle are the nitrogen fixers, nitrifiers, and denitrifiers. Photosynthesis by cyanobacteria generated the oxygen gas that permitted the evolution of aerobic respiration and the appearance of present-day eukaryotes. Archaea lying beneath the oceans prevent large deposits of methane, a "greenhouse gas," from accumulating in the oceans and the atmosphere. Many prokaryotes live in or on other organisms, with neutral, beneficial, or harmful effects. A small minority of bacteria are pathogens. Pathogens vary with respect to their invasiveness and toxigenicity. Some produce endotoxins, which are rarely fatal to their hosts; others produce exotoxins, which tend to be highly toxic. Prokaryotes and some unicellular eukaryotes form resistant biofilms that present medical and industrial problems. Prokaryote Phylogeny and Diversity Phylogenetic classification of prokaryotes is now based on rRNA sequences and other molecular evidence. Lateral gene transfer among prokaryotes, which has occurred throughout evolutionary history, makes it difficult to infer prokaryote phylogeny. Evolution, powered by mutation, natural selection, and genetic drift, can proceed rapidly in prokaryotes because they are haploid and can multiply rapidly. The Bacteria There are more known bacteria than known archaea. One phylogenetic classification of the domain Bacteria groups them into more than a dozen clades. Review Figure 27.8 The three clades that may contain the most ancient bacteria, like the most ancient archaea, are thermophiles, suggesting that life originated in a hot environment. All four nutritional types occur in the largest bacterial group, the proteobacteria. Metabolism in different groups of proteobacteria has evolved along different lines. Review Figure 27.9 Cyanobacteria, unlike other bacteria, photosynthesize using the same pathways plants use. Many cyanobacteria fix nitrogen. Spirochetes move by means of axial filaments. Chlamydias are tiny parasites that live within the cells of other organisms. Firmicutes are diverse; some of them produce endospores as resting structures that resist harsh conditions. Actinomycetes, some of which produce important antibiotics, grow as branching filaments. Mycoplasmas, the tiniest living things, lack conventional cell walls. They have very small genomes. The Archaea Archaea have cell walls lacking peptidoglycan, and their membrane lipids differ from those of bacteria and eukaryotes, containing branched long-chain hydrocarbons connected to glycerol by ether linkages. Review Figure 27.18 The domain Archaea can be divided into two principal groups,

Crenarchaeota and Euryarchaeota. Crenarchaeota are mostly heat-loving and often acid-loving archaea. Methanogens produce methane by reducing carbon dioxide. Some methanogens live in the guts of herbivorous animals; others occupy high-temperature environments on the ocean floor. Extreme halophiles are salt lovers that often lend a pinkish color to salty environments; some halophiles also grow in extremely alkaline environments. Archaea of the genus Thermoplasma lack cell walls, are thermophilic and acidophilic, and have a tiny genome (1,100,000 base pairs). Many archaea, including members of both major groups, live in environments that are not extreme. CHAPTER 28: PROTISTS AND THE DAWN OF THE EUKARYA Protists Defined In this book we define the protists simply as all eukaryotes that are not plants, fungi, or animals. The protists are a paraphyletic group, not a clade. The Origin of the Eukaryotic Cell The modern eukaryotic cell arose from an ancestral prokaryote in several steps. Probable steps include the loss of the cell wall and infolding of the plasma membrane. Review Figure 28.2 In subsequent steps, an infolded plasma membrane attached to the chromosome may have led to the formation of a nuclear envelope. A primitive cytoskeleton evolved. Review Figure 28.3 The first truly eukaryotic cell was larger than its prokaryote ancestor, was probably a phagocyte, and may have possessed one or more flagella of the eukaryotic type. The incorporation of prokaryotic cells as endosymbionts gave rise to eukaryotic organelles. Peroxisomes, which protected the host cell from an oxygen-rich atmosphere, may have been the first organelles of endosymbiotic origin. Mitochondria evolved from once free-living proteobacteria, and chloroplasts evolved from once free-living cyanobacteria. Review Figure 28.3 General Biology of the Protists Most protists are aquatic; some live within other organisms. The great majority are unicellular and microscopic, but many are multicellular and a few are enormous. "Protozoan" is an outdated term sometimes applied to protists, mostly ingestive heterotrophs, that were once classified as animals. "Alga" is an outdated term sometimes applied to photosynthetic protists. Protists vary widely in their modes of nutrition and locomotion. Some protist cells contain contractile vacuoles, and some digest their food in food vacuoles. Review Figures 28.5, 28.6. See Web/CD Tutorial 28.1 Protists have a variety of cell surfaces, some of them protective. Many protists contain endosymbionts. Some protists are endosymbionts in other cells, including other protists. Some endosymbiotic protists perform photosynthesis, to the advantage of their hosts. Most protists reproduce both asexually and sexually. Protist Diversity Molecular and other techniques are enabling biologists to identify many clades of protists. Review Table 28.1 and Figure 28.9 Diplomonads and Parabasalids Diplomonads and parabasalids may have the most ancient roots of today's protists. Both lack mitochondria, having apparently lost them during their evolution. Diplomonads have two nuclei and multiple flagella. Review Figure 28.10a Parabasalids have flagella and undulating membranes. Review Figure 28.10b Euglenozoans The euglenozoans are a clade of unicellular protists with flagella. Euglenoids are euglenozoans that are often photosynthetic and have anterior flagella. Review Figure 28.11 Kinetoplastids are euglenozoans that have a single, large mitochondrion, in which RNA is edited. Alveolates The alveolates are a clade of unicellular organisms with cavities, called alveoli, beneath their plasma membranes. Dinoflagellates are marine alveolates with a golden-brown color that results from their photosynthetic and accessory pigments. They are major contributors to

world photosynthesis. Many are endosymbionts; in that role they are important contributors to coral growth. Dinoflagellates are responsible for toxic "red tides." Apicomplexans are parasitic alveolates with an amoeboid body form. Their spores, containing a mass of organelles at the apical end, are adapted to the invasion of host tissue. The apicomplexan Plasmodium, which causes malaria, uses two alternate hosts (humans and Anopheles mosquitoes). Review Figure 28.14 Ciliates are alveolates that move rapidly by means of cilia and have two kinds of nuclei. The macronuclei control the cell by means of transcription and translation. The micronuclei are responsible for genetic recombination, accomplished by conjugation, a process that is sexual, but not reproductive. Review Figures 28.16, 28.17. See Web/CD Activity 28.1 Stramenopiles Stramenopiles typically have two flagella of unequal length, the longer bearing rows of tubular hairs. Some stramenopile groups are photosynthetic. Diatoms are unicellular stramenopiles, many of which have complex, two-part, glassy cell walls. They contribute extensively to world photosynthesis. Review Figure 28.19 The brown algae are predominantly multicellular, photosynthetic stramenopiles. They include the largest of all protists, and some show considerable tissue differentiation. In many multicellular photosynthetic protists and in all plants, both haploid and diploid cells undergo mitosis, leading to an alternation of generations. The diploid sporophyte generation forms spores by meiosis, and the spores develop into haploid organisms. This haploid gametophyte generation forms gametes by mitosis, and their fusion yields zygotes that develop into the next generation of sporophytes. Review Figure 28.22 Oomycetes are a group of nonphotosynthetic stramenopiles including water molds and downy mildews. The oomycetes are coenocytic. They are diploid for most of their life cycle. Red Algae Red algae are multicellular, photosynthetic protists. They differ from the other photosynthetic protist groups in having a characteristic storage product (floridean starch) and lacking flagellated reproductive cells. Chlorophytes The chlorophytes, a clade of green algae, are often multicellular. Like plants, they contain chlorophylls a and b and use starch as a storage product. The chlorophytes are sister to a clade that includes other green algae and the plant kingdom. The chlorophytes have diverse life cycles; among these are the isomorphic alternation of generations of Ulva and the haplontic life cycle of Ulothrix. Review Figures 28.26, 28.27. See Web/CD Activities 28.2 and 28.3 Choanoflagellates The choanoflagellates are colonial protists with flagella and a body type similar to the most characteristic type of cell found in sponges. The choanoflagellates are sister to the animal kingdom. A History of Endosymbiosis Primary endosymbiosis of a cyanobacterium and a eukaryote gave rise to the chloroplasts of green algae, plants, and red algae. Review Figure 28.29. See Web/CD Tutorial 28.2 Secondary endosymbioses of eukaryotes with unicellular green or red algae gave rise to the chloroplasts of euglenoids, stramenopiles, and other groups. One of those groups has given rise to another type of chloroplast by tertiary endosymbiosis. Some Recurrent Body Forms Some similar body forms are found in several different, unrelated protist groups. Amoebas, which appear in many protist groups, move by means of pseudopods. Actinopods have thin, stiff pseudopods that serve various functions, including food capture. Foraminiferans also use pseudopods for feeding, and they secrete shells of calcium carbonate. Acellular slime molds and cellular slime molds are superficially similar, moving as slimy masses and producing

stalked fruiting structures. However, they differ at the cellular level. Acellular slime molds are coenocytes with diploid nuclei. Cellular slime molds consist of individual haploid cells that aggregate into masses consisting of distinct cells. CHAPTER 29: PLANTS WITHOUT SEEDS: FROM SEA TO LAND The Plant Kingdom Plants are photosynthetic eukaryotes that develop from embryos protected by parental tissue. Like the green algae, they use chlorophylls a and b and store carbohydrates as starch. Review Figure 29.1 Plant life cycles feature alternation of gametophyte (haploid) and sporophyte (diploid) generations. Both generations include multicellular organisms. Review Figure 29.2 There are ten surviving phyla of plants. The three basal phyla are nontracheophytes, and the remaining seven phyla are tracheophytes. Review Table 29.1 Plants arose from a common green algal ancestor in the charophyte clade, either a stonewort or a member of the group that includes Coleochaete. Descendants of this ancestral charophyte colonized the land. The Conquest of the Land The acquisition of a cuticle, gametangia, a protected embryo, protective pigments, thick spore walls with a protective polymer, and a mutualistic association with a fungus are all defining characters of plants, and all are associated with the adaptation of plants to life on land. Tracheophytes are characterized by possession of a vascular system, consisting of water- and mineral-conducting xylem and nutrient-conducting phloem. Nontracheophytes lack a vascular system. Review Figure 29.4 The Nontracheophytes: Liverworts, Hornworts, and Mosses Nontracheophytes either lack vascular tissues completely or, in the case of certain mosses, have only a rudimentary system of water- and food-conducting cells. The nontracheophyte sporophyte generation is smaller than the gametophyte generation and depends on the gametophyte for water and nutrition. Review Figures 29.5, 29.6. See Web/CD Tutorial 29.1 The nontracheophytes include the liverworts (phylum Hepatophyta), hornworts (phylum Anthocerophyta), and mosses (phylum Bryophyta). Hornwort sporophytes grow at their basal end. Hornworts, mosses, and tracheophytes have surface pores (stomata) that allow gas exchange and minimize water loss. In mosses and tracheophytes, the sporophytes grow by apical cell division. The hydroids of mosses, through which water may travel, may be ancestral to tracheids, the water-conducting cells of the tracheophytes. Introducing the Tracheophytes The tracheophytes have vascular tissue with tracheids and other specialized cells designed to conduct water, minerals, and products of photosynthesis. Present-day tracheophytes are grouped into seven phyla. The two basal phyla are nonseed tracheophytes, and the rest are seed plants. Review Figure 29.10 In tracheophytes, the sporophyte is larger than the gametophyte and independent of the gametophyte generation. The earliest tracheophytes, known to us only in fossil form, lacked roots and leaves. Review Figure 29.12 Roots may have evolved from rhizomes or from branches that penetrated the ground. Microphylls are thought to have evolved from sporangia, and megaphylls may have resulted from the flattening and reduction of an overtopping, branching stem system. Review Figure 29.13 Heterospory, the production of distinct female megaspores and male microspores, evolved on several occasions from homosporous ancestors. Review Figure 29.14. See Web/CD Activities 29.1 and 29.2 The Surviving Nonseed Tracheophytes Club mosses (phylum Lycophyta) have microphylls arranged spirally. Among the pteridophytes (phylum Pteridophyta), horsetails have reduced megaphylls in whorls. Whisk ferns lack roots; one genus has minute scales rather than leaves, and the other has reduced megaphylls with vascular tissue.

Leaves with more complex vasculature are characteristic of all other phyla of tracheophytes. The ferns are not a clade, although 97 percent of fern species do constitute a clade. Ferns have megaphylls with branching vascular strands. Review Figure 29.20. See Web/CD Activity 29.3

CHAPTER 30: THE EVOLUTION OF SEED PLANTS The Seed Plants The seed plants (gymnosperms and angiosperms) are heterosporous and have greatly reduced gametophytes. Review Figures 30.1, 30.2 Modern gymnosperms and many angiosperms have abundant xylem and extensive secondary growth. Most modern seed plants have no swimming gametes and do not require liquid water for fertilization. The male gametophyte—the pollen grain—is dispersed by wind or by animals. The seed is a well-protected resting stage that often contains nutrients that support the growth of the embryo. The Gymnosperms: Naked Seeds The gymnosperms, once the dominant vegetation on Earth, still dominate forests in the northern parts of the Northern Hemisphere and at high elevations. The four surviving gymnosperm phyla are the Cycadophyta (perhaps the most ancient), Ginkgophyta (consisting of a single species, the maidenhair tree), Gnetophyta (which has some characters in common with the angiosperms), and Pinophyta (the familiar cone-bearing trees). Conifers have a life cycle in which naked seeds are produced on the scales of cones. Pollen is produced in strobili, which are smaller than cones. Pollen is transferred from strobili to cones by wind. Review Figures 30.5, 30.6. See Web/CD Tutorial 30.1 and Activity 30.1 The Angiosperms: Flowering Plants Angiosperms (phylum Angiospermae) are distinguished by double fertilization, which results in a triploid nutritive tissue, the endosperm. The ovules and seeds of angiosperms are enclosed by a carpel. Angiosperms are also characterized by the production of flowers and fruits. The vascular tissues of angiosperms contain three characteristic cell types: vessel elements, fibers, and companion cells. Woody angiosperms show secondary growth. Flowers are made up of various combinations of carpels, stamens, petals, and sepals. Perfect flowers have both carpels and stamens. Review Figure 30.7. See Web/CD Activity 30.2 Monoecious plant species have both female and male flowers on the same plant. In dioecious species, female and male flowers are found on separate individuals. Carpels and stamens may have evolved from leaflike structures. Review Figure 30.10 Angiosperms and the animals that pollinate them have coevolved. The angiosperm seed contains the products of double fertilization: the diploid zygote and the triploid endosperm. Review Figure 30.11 The largest clades of flowering plants, in terms of numbers of species, are the monocots and the eudicots. There are a few other angiosperm clades, notably the water lilies, star anise and its relatives, and the magnoliids. Review Figure 30.13 Amborella, a tropical shrub, is thought to be the sole living representative of the most ancient living angiosperm clade. The evolutionary origin of the angiosperms remains a mystery. CHAPTER 31: FUNGI: RECYCLERS, PATHOGENS, PARASITES, AND PLANTS PARTNERS General Biology of the Fungi Fungi are heterotrophic eukaryotes with absorptive nutrition and with chitin in their cell walls. They may be saprobes, parasites, or mutualists. These four fungal phyla differ in their reproductive structures, mechanisms of spore formation, and less importantly, the presence and form of septa in their hyphae. The yeasts

are unicellular fungi. The bodies of multicellular fungi are composed of multinucleate hyphae, often massed to form a mycelium. The hyphae usually have incomplete partitions (septa) that allow the movement of organelles between cells. They give fungi a large surface area-to-volume ratio, enhancing their ability to absorb nutrients. Review Figures 31.3, 31.4 Fungi reproduce asexually by means of spores formed within sporangia, by conidia formed at the tips of hyphae, by fission or budding, or by fragmentation. Fungi reproduce sexually when hyphae of different mating types meet and fuse. In addition to the haploid and diploid states, many fungi demonstrate a third nuclear condition: the dikaryotic, or n + n, state. Diversity in the Kingdom Fungi The kingdom Fungi consists of four phyla: Chytridiomycota, Zygomycota, Ascomycota, and Basidiomycota. Review Figure 31.6, Table 31.1. See Web/CD Activity 31.1 The chytrids, with their flagellated zoospores and gametes, probably resemble the ancestral fungi. The zygomycetes reproduce sexually by fusion of gametangia. Review Figure 31.9 The sexual reproductive structure of ascomycetes is an ascus containing ascospores. The ascomycetes are divided into two groups, euascomycetes and hemiascomycetes, on the basis of whether they have an ascocarp, or fruiting structure. Review Figure 31.13. See Web/CD Activity 31.2 The sexual reproductive structure of basidiomycetes is a basidium, a swollen cell bearing basidiospores. Review Figure 31.15 Imperfect fungi (deuteromycetes) lack sexual structures, but DNA sequencing can sometimes identify the phylum to which they belong. See Web/CD Tutorial 31.1 Fungal Associations Mycorrhizae, which are symbiotic associations of a fungus with plant roots, enhance the ability of the roots to absorb water and nutrients. In return, the plant supplies the fungus with photosynthetic products. Lichens, which are symbiotic associations of a fungus with a green alga or a cyanobacterium, are found in some of the most inhospitable environments on the planet. Review Figure 31.18 CHAPTER 32: ANIMAL ORIGINS AND THE EVOLUTION OF BODY PLANS Animals: Descendants of a Common Ancestor All members of the kingdom Animalia are believed to have a common ancestor, which was a colonial flagellated protist. The specialization of cells by function made possible the complex, multicellular body plan of animals. Animals are multicellular heterotrophs. They take in complex organic molecules, expending energy to do so. Morphological, developmental, and molecular data all support similar animal phylogenies. The two major animal lineages—protostomes and deuterostomes—are believed to have diverged early in animal evolution; they differ in several components of their early development. Review Figure 32.1 Body Plans Are Basic Structural Designs Most animals have either radial or bilateral symmetry. Radially symmetrical animals move slowly or not at all. Bilateral symmetry is strongly correlated with more rapid movement and the concentration of sense organs at the anterior end of the animal. Review Figure 32.2 The body cavity of an animal is strongly correlated with its ability to move. On the basis of their body cavities, animals are classified as acoelomates, pseudocoelomates, or coelomates. Review Figure 32.3 Sponges: Loosely Organized Animals Sponges (phylum Porifera) are simple animals that lack cell layers and true organs, but have several different cell types. Sponges feed by means of choanocytes, feeding cells that draw water through the sponge body and filter out food particles. Review Figure 32.4 Sponges come in a variety of sizes and shapes that are adapted to different movement patterns of water. Cnidarians: Two Cell Layers and Blind Guts Cnidarians (phylum Cnidaria) are radially symmetrical and diploblastic, but with their

nematocyst-studded tentacles, they can capture prey larger and more complex than themselves. Review Figure 32.7 Most cnidarian life cycles have a sessile polyp stage and a free-swimming, sexual, medusa stage, but some species lack one of the stages. Review Figures 32.8, 32.10, 32.11. See Web/CD Tutorial 32.1 Ctenophores: Complete Guts and Tentacles Ctenophores (phylum Ctenophora) are diploblastic marine carnivores with a complete gut and simple life cycles. Review Figure 32.12 The Evolution of Bilaterally Symmetrical Animals All bilaterally symmetrical animals probably share a common ancestor. Protostomes and deuterostomes are each monophyletic lineages that have been evolving separately since the Cambrian period. Their members are structurally more complex than cnidarians and ctenophores. Protostomes have a ventral nervous system, paired nerve cords, and larvae with compound cilia. Deuterostomes have a dorsal nervous system and larvae with a single cilium per cell. The protostomes split into two major groups: lophotrochozoans and ecdysozoans. Review Figure 32.14 Simple Lophotrochozoans Flatworms (phylum Platyhelminthes) are acoelomate, lack organs for oxygen transport, have only one entrance to the gut, and move by beating their cilia. Many species are parasitic. Review Figures 32.15, 32.16 Although they are no larger than many ciliated protists, rotifers (phylum Rotifera) have highly developed internal organs. Review Figure 32.17 Lophophorates: An Ancient Body Plan The lophotrochozoan lineage split into two branches, whose descendants became the modern lophophorates and the spiralians. The lophophore dominates the anatomy of many lophophorate animals. Review Figure 32.18 Ectoprocts are colonial lophophorates that can move their lophophores. Review Figure 32.19 Brachiopods, which superficially resemble bivalve mollusks, were much more abundant in the past than they are today. Spiralians: Spiral Cleavage and Wormlike Body Plans The spiralian lineage gave rise to many phyla, most of whose members are wormlike. Ribbon worms (phylum Nemertea) have a complete digestive tract and capture prey with an eversible proboscis. Review Figure 32.21 Annelids (phylum Annelida) are a diverse group of segmented worms that live in marine, freshwater, and terrestrial environments. Review Figure 32.22 Mollusks (phylum Mollusca) have a body plan with three basic components: foot, mantle, and visceral mass. Review Figure 32.25 The molluscan body plan has been modified to yield a diverse array of animals that superficially appear very different from one another. See Web/CD Activities 32.1 and 32.2 for a concept review of this chapter CHAPTER 33: ECDYSOZOANS: THE MOLTING ANIMALS The ecdysozoan lineage is characterized by a nonliving external covering an exoskeleton, or cuticle. Review Figure 33.1 An animal with an exoskeleton grows by periodically shedding its exoskeleton and replacing it with a larger one, a process called molting. Cuticles: Flexible, Unsegmented Exoskeletons Members of several phyla of marine worms with thin cuticles are descendants of an early split in the ecdysozoan lineage. Review Figure 33.3 Tough cuticles are found in members of two phyla, the horsehair worms and the roundworms. Roundworms (phylum Nematoda) are one of the most abundant and universally distributed of all animal groups. Many are parasites. Review Figure 33.5 Arthropods and Their Relatives: Segmented External Skeletons Animals with rigid exoskeletons lack cilia for locomotion. To move, they have appendages that can be manipulated by muscles. Review Figure 33.8 Although there is currently no consensus on an exact phylogeny, most researchers agree that the arthropod groups are monophyletic. Onychophorans and tardigrades have soft, unjointed legs.

They are probably similar to ancestral arthropods. Trilobites flourished in Cambrian and Ordovician seas, but they became extinct at the close of the Paleozoic era. Crustaceans: Species-Rich and Abundant The segments of the crustacean body are divided among three regions: head, thorax, and abdomen. Review Figure 33.10 The most familiar crustaceans are shrimp, lobsters, crayfish, crabs, sow bugs, and sand fleas. Copepod crustaceans may be the most abundant animals on the planet. Recent molecular evidence indicates that the crustacean lineage may be ancestral to all the arthropods. Insects: Terrestrial Descendants of Marine Crustaceans About 1.4 million species of insects (phylum Hexapoda) have been described, but that number is a small fraction of the total number of existing species. Although few species are found in marine environments, they are among the dominant animals in virtually all terrestrial and many freshwater habitats. Like crustaceans, insects have three body regions (head, thorax, abdomen). They bear a single pair of antennae on the head and three pairs of legs attached to the thorax. No appendages grow from their abdominal segments. Review Figure 33.11 Wingless insects look like miniature adults when they hatch. Hatchlings of some winged insects resemble adults, but others undergo substantial changes at each molt. The winged insects can be divided into three major subgroups. Members of one subgroup cannot fold their wings back against the body. Members of the other two subgroups can. The wings of insects probably evolved from the dorsal branches of multibranched ancestral appendages. Review Figure 33.14 Arthropods with Two Body Regions Individuals of the remaining arthropod phyla generally have segmented bodies with two distinct regions, head and trunk. Myriapods (centipedes and millipedes) have many segments and many pairs of legs. Most chelicerates (phylum Chelicerata) have four pairs of legs. Arachnids-scorpions, harvestmen, spiders, mites, and ticks–are abundant in terrestrial environments. Themes in the Evolution of Protostomes Most evolution of protostomes took place in the oceans. Early animals used fluid-filled body cavities as hydrostatic skeletons. Subdivision of the body cavity into segments allowed better control of movement. During much of animal evolution, the only food in the water consisted of dissolved organic matter and very small organisms. Flowing water brings food with it, allowing many aquatic animals to obtain food while being sessile. Predation may have been the major selective pressure for the development of hard, external body coverings. See Web/CD Activities 33.1 and 33.2 for a concept review of this chapter. CHAPTER 34: DEUTEROSTOMATE ANIMALS Origins of the Deuterostomes The deuterostomate lineage separated from the protostomate lineage early in animal evolution. The ancestral deuterostome had external gills. Review Figure 34.1 There are only two major deuterostomate lineages, and there are fewer species of deuterostomes than protostomes, but as members of the lineage, we have a special interest in its members. Review Figure 34.2. See Web/CD Activity 34.1 Echinoderms: Pentaradial Symmetry Echinoderms have a pentaradially symmetrical body plan, a unique water vascular system, and a calcified internal skeleton. Review Figure 34.3 Nearly all living species of echinoderms have a bilaterally symmetrical, ciliated larva that feeds as a planktonic organism. Review Figure 34.3 Six major groups of echinoderms survive today, but 23 other lineages existed in the past. Some groups of echinoderms have arms, but others do not. Hemichordates: Conservative Evolution Acorn worms and pterobranchs are similar to ancestral deuterostomes. Review Figure 34.5 Chordates: New Ways of Feeding Members of another deuterostomate lineage evolved

enlarged pharyngeal slits used as feeding devices and a dorsal supporting rod, the notochord. Most urochordates are sessile as adults and filter prey from seawater with large pharyngeal baskets. But some species retain their notochords and nerve cords as planktonic adults. Evolution of the Chordates Cephalochordates probably resemble the ancestors of all other chordates. Review Figure 34.7 Vertebrates evolved jointed internal skeletons that enabled them to swim rapidly. Early vertebrates used the pharyngeal basket to filter small animals from mud. Review Figures 34.8, 34.9 Jaws, which evolved from anterior gill arches, enabled their possessors to grasp and chew their prey. Jawed fishes rapidly became dominant animals in both marine and fresh waters. Review Figure 34.11 Fishes evolved two pairs of unjointed fins, with which they control their swimming movements and stabilize themselves in the water, and swim bladders, which help keep them suspended in open water. Ray-finned fishes come in a wide variety of sizes and shapes. Many species have complex social systems. Colonizing the Land: Obtaining Oxygen from the Air Two lineages of fishes—lobe-finned fishes and lungfishes—evolved jointed fins. Amphibians, the first terrestrial vertebrates, arose from lungfish ancestors. The 4,500 species of amphibians living today belong to three groups: caecilians, frogs and toads, and salamanders. Most amphibians live in water at some time in their lives, and their eggs must remain moist. Review Figure 34.16. See Web/CD Tutorial 34.1 Amniotes evolved eggs with shells impermeable to water and thus became the first vertebrates to be independent of water for reproduction. Review Figure 34.17. See Web/CD Activity 34.2 Modern reptiles are members of four lineages: snakes and lizards, tuataras, turtles and tortoises, and crocodilians. Review Figure 34.18 Dinosaurs rose to dominance about 215 mya and dominated terrestrial environments for about 150 million years until they became extinct about 65 mya. Some dinosaurs evolved feathers and were capable of flight. Birds: More Feathers and Better Flight Birds arose about 175 mya from feathered dinosaur ancestors. The 9,600 species of birds are characterized by feathers, high metabolic rates, and parental care. The Origin and Diversity of Mammals Mammals evolved during the Mesozoic era, about 225 mya. The eggs of mammals are fertilized within the body of the female, and embryos develop for some time within a uterus before being born. Mammals are unique in suckling their young with milk secreted by mammary glands. The three species of mammals in subclass Prototheria lay eggs, but all other mammals give birth to live young. Therian mammals are divided into two major groups: the marsupials, which give birth to tiny young that are, in most species, raised in a pouch on the female's belly, and the eutherians, which give birth to relatively well-developed offspring. Primates and the Origin of Humans The primates split into two major lineages, one leading to the prosimians (lemurs and lorises) and the other leading to the tarsiers, monkeys, apes, and humans. Review Figure 34.25 Hominids evolved in Africa from terrestrial, bipedal ancestors. Review Figure 34.29 Early humans evolved large brains, language, and culture. They manufactured and used tools, developed rituals, and domesticated plants and animals. In combination, these traits enabled humans to increase greatly in number and to transform the face of Earth. Deuterostomes and Protostomes: Shared Evolutionary Themes Both protostomes and deuterostomes evolved structures to filter prey from the water, mechanisms to control their buoyancy in water, and planktonic larval stages. See Web/CD Activity 34.3 for a concept review of this chapter. CHAPTER 35: THE PLANT BODY Vegetative Organs of the Flowering

Plant Body Monocots typically have a single cotyledon, narrow leaves with parallel veins, flower parts in threes or multiples of three, and stems with scattered vascular bundles. Review Figure 35.1 Eudicots typically have two cotyledons, broad leaves with netlike veins, flower parts in fours or fives, and vascular bundles in a ring. Review Figure 35.1 Flowering plants that are neither monocots nor eudicots are generally similar in structure to eudicots. The vegetative organs of flowering plants are roots, which form a root system, and stems and leaves, which form a shoot system. Review Figure 35.2 Roots anchor the plant and take up water and minerals. Stems bear leaves and buds. Lateral buds form branches. Apical buds produce cells that contribute to the elongation of the stem. Leaves are responsible for most photosynthesis, for which their flat blades, held perpendicular to the sun's rays, are well adapted. Review Figure 35.5 Plant Cells The walls of plant cells have a structure that often corresponds to the special functions of the cell. The walls of individual cells are separated by a middle lamella common to two neighboring cells; each cell also has its own primary wall. Review Figure 35.6 Some cells produce a thick secondary wall. Adjacent cells are connected by plasmodesmata. Review Figures 35.7, 35.8 Parenchyma cells have thin walls. Many parenchyma cells store starch or lipids; some others carry out photosynthesis. Review Figure 35.9a Collenchyma cells provide flexible support. Review Figure 35.9b Sclerenchyma cells provide strength and often function when dead. Review Figure 35.9c, 35.9d Tracheids and vessel elements are xylem cells that conduct water and minerals after the cells die. Review Figures 35.9e, 35.10 Sieve tube elements are the conducting cells of the phloem. Their activities are often controlled by companion cells. Review Figure 35.11 Plant Tissues and Tissue Systems Three tissue systems extend throughout the plant body. The vascular tissue system, consisting of xylem and phloem, conducts water, minerals, and the products of photosynthesis throughout the plant body. The dermal tissue system protects the body surface. The ground tissue system produces and stores nutrient materials and performs other functions. Review Figure 35.12 Forming the Plant Body The pattern of cells and tissues along the long axis and the concentric arrangement of the tissue systems are parts of the plant body plan; they arise through orderly development. The plant body consists of semi-independent modules or units. The growth of stems and roots is indeterminate. Leaves, flowers, and fruits show determinate growth. Meristems are localized regions of cell division. A hierarchy of meristems generates the plant body. Apical meristems at the tips of stems and roots produce the primary tissues of those organs. Review Figure 35.13 Shoot apical meristems and root apical meristems give rise to primary meristems: the protoderm, the ground meristem, and the procambium. The protoderm produces the dermal tissue system, the ground meristem produces the ground tissue system, and the procambium produces the vascular tissue system. In some plants, the products of primary growth constitute the entire plant body. Many other plants show secondary growth. Two lateral meristems, the vascular cambium and cork cambium, are responsible for secondary growth. Review Figure 35.13 The structure of a winter woody twig reflects both primary and secondary growth. Review Figure 35.14 The young root has an apical meristem that gives rise to the root cap and to the three primary meristems, which in turn produce the three tissue systems. Root tips have three overlapping zones: the zone of cell division, the zone of cell elongation, and the zone of maturation. Review Figure 35.15 The protoderm

gives rise to the epidermis, part of which forms the root hairs that are responsible for absorbing water and minerals. Review Figure 35.16 The ground tissue system of a young root is the cortex, whose innermost cell layer, the endodermis, controls access to the stele. The stele, consisting of the pericycle, xylem, and phloem, is the root's vascular tissue system. Lateral roots arise in the pericycle. Review Figure 35.17. See Web/CD Activities 35.1 and 35.2 The shoot apical meristem also gives rise to three primary meristems, with roles similar to their counterparts in the root. Leaf primordia on the sides of the apical meristem develop into leaves. The vascular tissue in young stems is divided into vascular bundles, each containing both xylem and phloem. Pith occupies the center of the eudicot stem, and cortex lies outside the ring of vascular bundles, with pith rays lying between the vascular bundles. Review Figure 35.18. See Web/CD Activities 35.3 and 35.4 Many eudicot stems and roots show secondary growth in which vascular cambia and cork cambia give rise, respectively, to secondary xylem (wood) and secondary phloem and to cork. Review Figure 35.19. See Web/CD Tutorial 35.1 The vascular cambium lays down layers of secondary xylem and phloem. Living cells within these tissues are nourished by vascular rays. Review Figure 35.20 The periderm consists of cork, cork cambium, and phelloderm, all pierced at intervals by lenticels that allow gas exchange. Leaf Anatomy Supports Photosynthesis The photosynthetic tissue of a leaf is called mesophyll. Veins bring water and minerals to the mesophyll and carry the products of photosynthesis to other parts of the plant body. A waxy cuticle retards water loss from the leaf and is impermeable to carbon dioxide. Guard cells control the opening of stomata, openings in the leaf that allow CO_2 to enter, but also allow some water to escape. Review Figure 35.23. See Web/CD Activity 35.5

CHAPTER 36: TRANSPORT IN PLANTS Uptake and Movement of Water and Solutes Plant roots take up water and minerals from the soil. Review Figure 36.1 Water moves through biological membranes by osmosis, always moving toward cells with a more negative water potential. The water potential of a cell or solution is the sum of the solute potential and the pressure potential. All three parameters are expressed in megapascals (MPa). Review Figure 36.2 Mineral uptake requires transport proteins. Some minerals enter the plant by facilitated diffusion; others enter by active transport. A proton pump facilitates the active transport of many mineral ions across membranes in plants. Review Figure 36.3 Water and minerals pass from the soil to the xylem by way of the apoplast and symplast. In the root, water and minerals can move from the cortex into the stele only by way of the symplast because Casparian strips in the endodermis block their movement through the apoplast. Review Figures 36.4, 36.5. See Web/CD Activity 36.1 Transport of Water and Minerals in the Xylem Early experiments established that xylem sap does not move via the pumping action of living cells. Root pressure is responsible for guttation and for the oozing of sap from cut stumps, but it cannot account for the ascent of xylem sap in trees. Water transport in the xylem is the result of the combined effects of transpiration, cohesion, and tension. Evaporation from the leaf produces tension in the mesophyll cells, which pulls a column of water—held together by cohesion—up through the xylem

from the root. Dissolved minerals are carried passively in the water. Review Figure 36.8 Evaporation of water cools the leaves, but a plant cannot afford to lose too much water. Support for the transpiration-cohesion-tension model of water transport comes from studies using a pressure bomb. Review Figure 36.9 The role of transport in the xylem depends on several factors, including the K+ concentration. Review Figure 36.10 Transpiration and the Stomata Transpirational water loss is minimized by the waxy cuticle of the leaves. Stomata allow a compromise between water retention and carbon dioxide uptake. A pair of guard cells controls the size of the stomatal opening. A proton pump, activated by blue light, pumps protons from the guard cells to surrounding epidermal cells, setting up a proton gradient that drives the active transport of potassium ions into the cells. Water follows osmotically, swelling the cells and opening the stomata. Carbon dioxide and water levels in the leaf also affect stomatal opening. Review Figure 36.11 Translocation of Substances in the Phloem Products of photosynthesis, as well as some minerals, are translocated through sieve tubes in the phloem by way of living sieve tube elements. Review Figure 36.12 Translocation in the phloem can proceed in both directions in the stem, although in a single sieve tube it goes only one way. Translocation requires a supply of ATP. Translocation in the phloem is explained by the pressure flow model: The difference in solute concentration between sources and sinks creates a difference in pressure potential along the sieve tubes, resulting in bulk flow. Review Figure 36.14, Table 36.1. See Web/CD Tutorial 36.1 The validity of the pressure flow model is supported by the facts that the sieve plates are normally unobstructed, allowing bulk flow, and that the neighboring cells load organic solutes into the sieve tube elements in source regions and unload them in sink regions. The distribution and properties of plasmodesmata differ between source and sink tissues. It may become possible to regulate plasmodesma permeability in crop plants. CHAPTER 37: PLANT NUTRITION The Acquisition of Nutrients Plants are photosynthetic autotrophs that can produce all the organic compounds they need from carbon dioxide, water, and minerals, including a nitrogen source. They obtain energy from sunlight, carbon dioxide from the atmosphere, and nitrogen-containing ions and mineral nutrients from the soil. Plants explore their surroundings by growing rather than by movement. Mineral Nutrients Essential to Plants Plants require 14 essential mineral elements, all of which come from the soil solution. Several of these essential elements fulfill multiple roles. Review Table 37.1 The six mineral nutrients required in substantial amounts are called macronutrients; the eight required in much smaller amounts are called micronutrients. Review Table 37.1 Deficiency symptoms suggest what essential element a plant lacks. Review Table 37.2 Biologists discovered the requirement for each essential element by growing plants on hydroponic solutions lacking that element. Review Figure 37.1. See Web/CD Tutorial 37.1 Soils and Plants Soils are complex systems with living and nonliving components. They contain water, air, and inorganic and organic substances. They typically consist of two or three horizontal zones called horizons. Review Figures 37.2, 37.3 Soils form by mechanical and chemical weathering of rock. Plants obtain some mineral nutrients through ion exchange between the soil solution and the surface of clay particles. Review Figure 37.4 Farmers use fertilizers to make up for deficiencies in soil mineral nutrient content, and they apply lime to raise low soil pH. Plants affect soils in various ways, such as by adding organic material,

removing nutrients (especially in agriculture), and changing pH. Nitrogen Fixation A few species of soil bacteria are responsible for almost all nitrogen fixation. Some nitrogen-fixing bacteria live free in the soil; others live symbiotically as bacteroids within the roots of plants. In nitrogen fixation, nitrogen gas (N2) is reduced to ammonia (NH3) or ammonium ions (NH4+) in a reaction catalyzed by nitrogenase. Review Figure 37.6 Nitrogenase requires anaerobic conditions, but the bacteroids in root nodules require oxygen for their respiration. Leghemoglobin helps maintain the oxygen supply to the bacteroids at the proper level. The formation of a nodule requires an interaction between the root system of a legume and Rhizobium bacteria. Review Figure 37.7 Nitrogen-fixing bacteria reduce atmospheric N2 to ammonia, but most plants take up both ammonium ions and nitrate ions. Nitrifying bacteria oxidize ammonia to nitrate. Plants take up nitrate and reduce it back to ammonia, a feat of which animals are incapable. Review Figure 37.8. See Web/CD Activity 37.1 Denitrifying bacteria return N2 to the atmosphere, completing the global nitrogen cycle. Review Figure 37.8 Carnivorous and Heterotrophic Plants Carnivorous plant species are autotrophs that supplement their nitrogen supply by feeding on insects. A few heterotrophic plants are parasitic on other plants. Some parasitic plants have major effects on crops, especially in developing countries. CHAPTER 38: REGULATION OF PLANT GROWTH Interacting Factors in Plant Development The environment, photoreceptors, hormones, and the plant's genome all play roles in the regulation of plant development. Hormones mediate many developmental phenomena in plants. Each plant hormone plays multiple regulatory roles, affecting several different aspects of development. Interactions among the hormones are often complex. Review Table 38.1 Hormones and photoreceptors act through signal transduction pathways. An Overview of Plant Development Cell division, cell expansion, and cell differentiation all contribute to plant development. When seed dormancy ends, the seed germinates and develops into a growing seedling. Photoreceptors and hormones regulate seedling development. Review Figure 38.1. See Web/CD Activities 38.1 and 38.2 Eventually the plant flowers and forms fruit. Flowering in some plants is controlled by the length of the night. Hormones, probably including a flowering hormone, play roles in plant reproduction. Some plant buds exhibit winter dormancy. Eventually, all plants senesce and die. Dormancy and senescence are triggered by environmental cues, mediated by photoreceptors and hormones. Ending Seed Dormancy and Beginning Germination Seed dormancy may be caused by exclusion of water or oxygen from the embryo, mechanical restraint of the embryo, or chemical inhibition of embryonic development. In nature, seed dormancy is broken by various mechanisms, including abrasion, fire, leaching, and low temperatures. Seed dormancy offers adaptive advantages, such as an increased likelihood of germination in a place and at a time favorable for seedling growth. Seed germination begins with the imbibition of water. Then the embryo mobilizes its reserves to obtain chemical building blocks and energy. The embryos of cereal seeds secrete gibberellins, which cause the aleurone layer to synthesize and secrete digestive enzymes that break down large molecules stored in the endosperm. Review Figure 38.4. See Web/CD Activity 38.3 Gibberellins: Regulators from Germination to Fruit Growth There are dozens of gibberellins. One, gibberellin A1, regulates stem growth in most plants. Mutant plants that cannot produce normal amounts of gibberellins are dwarfs: Their stems are shorter than wild-type stems. Gibberellins

regulate the growth of some fruits and cause bolting in some biennial plants. Review Figure 38.6 Auxin Affects Plant Growth and Form Studies of phototropism led to the discovery and isolation of auxins such as indoleacetic acid. In grass seedlings, the photoreceptor for phototropism is in the tip of the coleoptile. An auxin signal moves from the photoreceptor to the growing region of the coleoptile. Review Figures 38.7, 38.8. See Web/CD Tutorial 38.2 Auxin transport is polar. Auxin anion efflux carriers, membrane proteins confined to the basal ends of cells, cause auxin to move from the tip to the base of the shoot. Review Figure 38.9 Lateral movement of auxin, mediated by auxin carrier proteins, is responsible for phototropism and gravitropism. Review Figure 38.10 Auxin plays roles in root formation, leaf abscission, apical dominance, and parthenocarpic fruit development. Certain synthetic auxins are used as selective herbicides. Review Figure 38.12 The arrangement of cellulose microfibrils in the plant cell wall limits the direction of cell expansion. Auxin increases the plasticity of the cell wall, promoting cell expansion. It does so by increasing the pumping of protons from the cytoplasm into the cell wall, where the lowered pH activates proteins called expansins. Review Figures 38.14, 38.15. See Web/CD Tutorial 38.3 Like all plant hormones, auxin is bound by receptor proteins. Auxin and other plant hormones signal cell differentiation and organ formation. See Web/CD Tutorial 38.1 Cytokinins Are Active from Seed to Senescence Cytokinins are adenine derivatives. Zeatin and isopentenyl adenine are naturally occurring cytokinins, and kinetin is a synthetic cytokinin. First studied as promoters of plant cell division, cytokinins also promote seed germination in some species, inhibit stem elongation, promote lateral swelling of stems and roots, stimulate the growth of lateral buds, promote the expansion of leaf tissue, and delay leaf senescence. Ethylene: A Hormone that Hastens Leaf Senescence and Fruit Ripening A balance between auxin and ethylene controls leaf abscission. Ethylene promotes senescence and fruit ripening. Ethylene causes the formation of a protective apical hook in eudicot seedlings that have not been exposed to light. In stems, it inhibits elongation, promotes lateral swelling, and causes a loss of gravitropic sensitivity. Ethylene acts through a signal transduction pathway that includes two membrane proteins and leads to the expression of genes. Review Figure 38.17 Abscisic Acid: The Stress Hormone Abscisic acid appears to maintain winter dormancy in buds. It prevents seeds from germinating while still attached to the parent plant, and it inhibits stem elongation. Through its effects on stomatal opening, it also regulates gas and water exchange between leaves and the atmosphere. Brassinosteroids: Hormones that Mediate Effects of Light There are dozens of brassinosteroids. These steroid hormones affect cell elongation, pollen tube elongation, vascular tissue differentiation, and root elongation. Some effects of light are mediated by changes in the action and levels of brassinosteroids. Light and Photoreceptors Phytochromes are bluish pigments found in the cytosol. Each phytochrome exists in two forms, Pr and Pfr, that are interconvertible by light. Pr absorbs red light and is converted to Pfr; Pfr absorbs far-red light and is converted to Pr. Pfr reverts to Pr in complete darkness. Review Figure 38.18 Phytochromes have effects on seedling growth, flowering, and etiolation. The five known phytochromes mediate the effects of red, far-red, and low-energy blue light. They may play different roles in plant development, and their signal transduction pathways may interact to mediate the effects of light environments of differing spectral

distribution. Cryptochromes, yellow pigments that absorb blue and ultraviolet light, interact with phytochromes in controlling seedling development and floral initiation. Cryptochromes mediate the effects of high-energy blue light. The signaling pathways for phytochromes and cryptochromes are based on protein kinases. Phototropin, another yellow pigment, is the photoreceptor for phototropism. Review Figure 38.19 Zeaxanthin, yet another blue-light receptor, mediates the light-induced opening of stomata. CHAPTER 39: REPRODUCTION IN FLOWERING PLANTS Many Ways to Reproduce Almost all flowering plants reproduce sexually, and many also reproduce asexually. Both sexual and asexual reproduction are important in agriculture. Sexual Reproduction in Plants Sexual reproduction promotes genetic diversity in a population, which may give the population an advantage under changing environmental conditions or in exploiting new territory. The flower is an angiosperm's device for sexual reproduction. Flowering plants have microscopic gametophytes that develop within the flowers of the sporophytes. The megagametophyte is the embryo sac, which typically contains eight nuclei in a total of seven cells. The microgametophyte is the pollen grain, which usually contains two cells. Review Figure 39.1. See Web/CD Tutorial 39.1 Pollination enables fertilization in the absence of external water. In self-incompatible species, the stigma or style rejects pollen from the same plant. Review Figure 39.3 The pollen grain delivers sperm cells to the embryo sac by means of a pollen tube. Most angiosperms perform double fertilization: One sperm nucleus fertilizes the egg, forming a zygote, and the other sperm nucleus unites with the two polar nuclei to form a triploid endosperm. Review Figure 39.5 The zygote develops into an embryo (with an attached suspensor), which remains quiescent in the seed until conditions are right for germination. The endosperm supplies the nutritive reserve upon which the embryo depends at germination. Review Figures 39.6, 39.7. See Web/CD Activity 39.1 Flowers develop into seed-bearing fruits, which often play important roles in the dispersal of the species. The Transition to the Flowering State For a vegetatively growing plant to flower, an apical meristem in the shoot system must become an inflorescence meristem, which gives rise to bracts as well as more meristems. The meristems it produces may become floral meristems or additional inflorescence meristems. Review Figure 39.9 Flowering results from a cascade of gene expression. Floral organ identity genes are expressed in floral meristems that give rise to sepals, petals, stamens, and carpels. Photoperiodic Control of Flowering Photoperiodic plants regulate their flowering by measuring the length of light and dark periods. Short-day plants flower when the days are shorter than a species-specific critical day length; long-day plants flower when the days are longer than a critical day length. Review Figure 39.10 Some angiosperms have more complex photoperiodic requirements than short-day or long-day plants have, but most are day-neutral. The length of the night is what actually determines whether a photoperiodic plant will flower. Review Figure 39.11 Interruption of the nightly dark period by a brief exposure to light undoes the effect of a long night. Review Figure 39.12. See Web/CD Tutorial 39.2 The mechanism of photoperiodic control involves phytochromes and a biological clock. Review Figures 39.13, 39.14 Evidence suggests that there is a flowering hormone, called florigen, but the substance has yet to be isolated from any plant. Review Figure 39.15 Vernalization and Flowering In some plant species, exposure to low temperatures–vernalization–is required for flowering. Asexual

Reproduction Asexual reproduction allows rapid multiplication of organisms that are well suited to their environment. Vegetative reproduction involves the modification of a vegetative organ–usually the stem–for reproduction. Stolons, tip layers, tubers, rhizomes, bulbs, corms, and suckers are means by which plants may reproduce vegetatively. Some plant species produce seeds asexually by apomixis. Agriculturalists use natural and artificial techniques of asexual reproduction to reproduce particularly desirable plants. Horticulturists often graft different plants together to take advantage of favorable properties of both stock and scion. Review Figure 39.17 Tissue culture techniques, made possible by the totipotency of many plant cells, are used to propagate plants asexually, to produce virus-free clones of crop plants, and to manipulate plants by recombinant DNA technology. CHAPTER 40: PLANT RESPONSES TO ENVIRONMENTAL CHALLENGES Plant-Pathogen Interactions Plants and pathogens evolve together in a continual "arms race." Review Figure 40.1. See Web/CD Tutorial 40.1 Plants can strengthen their cell walls when attacked. Plant chemical defenses include PR proteins and phytoalexins. In the hypersensitive response, cells produce phytoalexins and then die, trapping the pathogens in dead tissue. The hypersensitive response is often followed by systemic acquired resistance, in which the hormone salicylic acid activates further synthesis of PR proteins and triggers responses in other parts of the plant. A specific response, called gene-for-gene resistance, matches up alleles in a plant's resistance genes and a pathogen's avirulence genes. Review Figure 40.3 Plants use short interfering RNAs (siRNAs) to develop immunity to invading RNA viruses. Plants and Herbivores: Benefits and Losses Grazing by herbivores increases the productivity of some plants. Review Figure 40.4 Some plants produce secondary metabolites that function as chemical defenses against herbivores. Review Table 40.1 Various hormones, including systemin and jasmonates, participate in the pathways leading to the production of defensive chemicals. Review Figure 40.5 To avoid poisoning themselves, plants may confine the toxic substances they produce to special compartments, produce those substances only after cells have been damaged, or form enzymes and receptors that are not affected by the substances. Water Extremes: Dry Soils and Saturated Soils Desert annuals evade drought by living only long enough to take advantage of the brief period during which the soil has enough moisture to support them. Some leaves have special adaptations to dry environments: a thickened cuticle, epidermal hairs, sunken stomata, fleshy leaves and stems, spines, and altered leaf display angles. Other adaptations to dry environments include long taproots and root systems that die back seasonally. The submerged roots of some plants form pneumatophores to allow oxygen uptake from the air. Aerenchyma in submerged plant parts stores and permits the diffusion of oxygen. Review Figure 40.12 Too Much Salt: Saline Environments A saline environment restricts the availability of water to plants. Halophytes are plants that are adapted to such environments. Most halophytes accumulate salt. Some have salt glands that excrete the salt to the leaf surface. Halophytes and xerophytes have some adaptations in common. Review Figure 40.14 Habitats Laden with Heavy Metals Chromium, mercury, lead, and cadmium are among the heavy metals that are toxic to plants at high concentrations. Rather than excluding heavy metals, tolerant plants deal with them after taking them up. A given plant's tolerance is limited to only one or two heavy metals. Hot and Cold Environments High temperatures destabilize cell membranes and

some proteins. Adaptations to elevated temperatures include the production of heat shock proteins. Low temperatures cause membranes to lose their fluidity. Plants may respond to cooler temperatures with a change in membrane fatty acid composition. Ice crystals can puncture organelles and plasma membranes. Plant adaptations to freezing temperatures include the production of antifreeze proteins.

CHAPTER 41: PHYSIOLOGY, HOMEOSTASIS, AND TEMPERATURE REGULATION
Homeostasis: Maintaining the Internal Environment The internal environment consists of extracellular fluid. Organs and organ systems are specialized to keep certain aspects of the internal environment in a constant state. Review Figure 41.1 Homeostasis is the maintenance of a constant internal environment. Tissues, Organs, and Organ Systems Cells that have a similar structure and function make up a tissue. There are four general types of tissues: epithelial, connective, muscle, and nervous. Review Figure 41.2 Organs consist of multiple tissue types and make up organ systems. Review Table 41.1 See Web/CD Activity 41.1 Physiological Regulation and Homeostasis Homeostasis depends on the ability to control and regulate the functions of organs and organ systems. Regulatory systems have set points and respond to feedback information. Negative feedback corrects deviations from the set point, positive feedback amplifies responses, and feedforward information changes the set point. Review Figure 41.4 See Web/CD Tutorial 41.1 Temperature and Life Living systems require a range of temperatures between the freezing point of water and the temperatures that denature proteins. Most biological processes and reactions are temperature-sensitive. Q10 is a measure of temperature sensitivity. Review Figure 41.5 Animals that cannot avoid seasonal changes in body temperature have biochemical adaptations that compensate for those changes. These adaptations enable animals to acclimatize to seasonal changes. Review Figure 41.6 Maintaining Optimal Body Temperature Homeotherms maintain a fairly constant body temperature most of the time; poikilotherms do not. Endotherms produce metabolic heat to elevate body temperature; ectotherms depend mostly on environmental sources of heat. Review Figure 41.7 Ectotherms and endotherms can regulate body temperature through behavior. Review Figure 41.8 Heat exchange between a body and the environment occurs via radiation, conduction, convection, and evaporation. Review Figure 41.10 Ectotherms and endotherms can control heat exchange with the environment by altering blood flow to the skin. Review Figure 41.11 Some ectotherms can produce metabolic heat to raise their body temperatures. Some fishes have circulatory systems that function as countercurrent heat exchangers to conserve heat produced by muscle metabolism. Review Figure 41.12 Thermoregulation in Endotherms Endotherms have high basal metabolic rates. Over a range of environmental temperatures called the thermoneutral zone, the metabolic rate of resting endotherms remains at basal levels. The basal metabolic rate per gram of tissue decreases as endotherms get bigger. Review Figures 41.13, 41.14 See Web/CD Activity 41.2 When the environmental temperature falls below the lower critical temperature, endotherms maintain their body temperatures through shivering and nonshivering metabolic heat production. Review Figure 41.15 Endotherms that live in cold climates have adaptations that minimize heat

loss, including a reduced surface area-to-volume ratio and increased insulation. When the environmental temperature rises above an upper critical temperature, metabolic rate increases as a consequence of active evaporative water loss through sweating or panting. The Vertebrate Thermostat The vertebrate thermostat is located in the hypothalamus. It has set points for activating thermoregulatory responses. In mammals, cooling the hypothalamus induces the constriction of blood vessels and increased metabolic heat production. Heating the hypothalamus induces the dilation of blood vessels and panting. Review Figure 41.17 Changes in the set point reflect the integration of information, such as environmental temperature and time of day, that is relevant to the regulation of body temperature. Review Figure 41.18 Fever, which results from a rise in the set point, helps the body fight infections. Adaptations in which set points are reduced to conserve energy include daily torpor and hibernation. Review Figure 41.19 CHAPTER 42: ANIMAL HORMONES Hormones and Their Actions Endocrine cells secrete chemical messages called hormones, which bind to receptors on or in target cells. Most hormones are peptides, proteins, steroids, or amines . Peptide and protein hormones and some amines are water-soluble; steroids and some amines are lipid-soluble. The receptors for water-soluble hormones are on the cell surface. The receptors for lipid-soluble hormones are inside the cell. Some hormones diffuse to targets near the site of secretion. Autocrine hormones influence the cell that secretes them; paracrine hormones influence nearby cells. Review Figure 42.1 Most hormones are distributed throughout the body by the circulatory system. Hormones cause different responses in different target cells. Hormones may be secreted by single cells or by cells organized into discrete endocrine glands. Review Figure 42.2 See Web/CD Activity 42.1 Hormonal Control of Molting and Development in Insects Insects must molt their exoskeletons to grow. Two diffusible substances, brain hormone and ecdysone, control molting. Review Figure 42.3 Juvenile hormone, another diffusible substance, prevents maturation so that juvenile instars molt into larger juvenile instars. When the insect stops producing juvenile hormone, it molts into an adult. Some insects undergo complete metamorphosis. When juvenile hormone drops to a low level, the larval form molts into a pupa. Because no juvenile hormone is secreted during pupation, the pupa molts into an adult. Review Figure 42.4 See Web/CD Tutorial 42.1 Vertebrate Endocrine Systems Vertebrates have nine major endocrine glands that secrete many hormones. Review Figure 42.2, Table 42.1 The pituitary gland is divided into two parts. The anterior pituitary develops from embryonic mouth tissue; the posterior pituitary develops from the brain. The posterior pituitary secretes two neurohormones, antidiuretic hormone and oxytocin. Review Figure 42.5 The anterior pituitary secretes tropic hormones (thyrotropin, adrenocorticotropin, luteinizing hormone, and follicle-stimulating hormone), as well as growth hormone, prolactin, melanocyte-stimulating hormone, endorphins, and enkephalins. The anterior pituitary is controlled by neurohormones produced by cells in the hypothalamus and transported through portal blood vessels to the anterior pituitary. Review Figure 42.7, Table 42.2 See Web/CD Tutorial 42.2 Hormone release in the hypothalamus-pituitary-endocrine gland system is controlled by negative feedback loops. Review Figure 42.8 The thyroid gland is controlled by thyrotropin and secretes thyroxine, which controls cell metabolism. The level of calcium in the blood is regulated by three hormones. Calcitonin lowers blood calcium by promoting bone deposition.

Parathyroid hormone raises blood calcium by promoting bone turnover and decreased calcium excretion. Vitamin D promotes calcium absorption from the digestive tract. Review Figure 42.9 See Web/CD Tutorial 42.3 The pancreas secretes three hormones. Insulin stimulates glucose uptake by cells and lowers blood glucose, glucagon raises blood glucose, and somatostatin slows the rate of nutrient absorption from the gut. The adrenal gland has two portions, one within the other. The hormones of the adrenal medulla, epinephrine and norepinephrine, stimulate the liver to supply glucose to the blood, as well as other fight-or-flight reactions. Review Figure 42.10 The adrenal cortex produce three classes of corticosteroids: glucocorticoids, mineralocorticoids, and small amounts of sex steroids. Review Figure 42.11 Aldosterone is a mineralocorticoid that stimulates the kidney to conserve sodium and to excrete potassium. Cortisol is a glucocorticoid that decreases glucose utilization by most cells. Sex hormones (androgens in males, estrogens and progesterone in females) are produced by the gonads in response to tropic hormones. Sex hormones control sexual development, secondary sexual characteristics, and reproductive functions. Review Figure 42.12 The pineal hormone melatonin is involved in controlling biological rhythms and photoperiodism. Review Figure 42.13 Hormone Actions: The Role of Signal Transduction Pathways The response of a cell to a hormone depend on what receptors it has and what signal transduction pathways those receptors activate. Review Table 42.3 and Figure 42.14 The sensitivity of a cell to hormones can be altered by up- or downregulation of the receptors in that cell. Immunoassays are used to measure concentrations of hormones and receptors. Review Figure 42.15 Important tools for characterizing hormone action are dose-response curves and measurements of half-life. Review Figure 42.16 The time course of a response to a hormone depends on many factors, including binding of the hormone to carrier proteins and elimination of the hormone through degradation and excretion. See Web/CD Activity 42.2 for a concept review of this chapter. CHAPTER 43: ANIMAL REPRODUCTION Asexual Reproduction Some animals can reproduce asexually, producing offspring that are genetically identical to their parent and to one another. A disadvantage of asexual reproduction is that no genetic diversity is produced. Means of asexual reproduction include budding, regeneration, and parthenogenesis. Review Figures 43.1, 43.2 Sexual Reproduction Sexual reproduction consists of three basic steps: gametogenesis, mating, and fertilization. Gametogenesis and fertilization are similar in all animals, but mating includes a great variety of anatomical, physiological, and behavioral adaptations. In sexually reproducing species, genetic diversity is created by crossing over and independent assortment of chromosomes during gametogenesis. Fertilization also contributes to genetic diversity. Gametogenesis occurs in testes and ovaries. In spermatogenesis (the production of sperm) and oogenesis (the production of eggs), the germ cells proliferate mitotically, undergo meiosis, and mature into gametes. Each primary spermatocyte can produce four haploid sperm through the two divisions of meiosis. Review Figure 43.3a Primary oocytes immediately enter prophase of the first meiotic division, and in many species, including humans, their development is arrested at this point. Each oogonium produces only one egg. Review Figure 43.3b Fertilization involves sperm activation, species-specific binding of sperm to egg, the acrosomal reaction, digestion of a path through the protective coverings of the egg, and fusion of sperm and egg plasma membranes. Review Figures 43.4, 43.5 See Web/CD Tutorial 43.1 The

fusion of the sperm and egg plasma membranes triggers fast and slow blocks to polyspermy, which prevent additional sperm from entering the egg, and in mammals, signals the egg to complete meiosis and begin development. Review Figure 43.6 Fertilization can occur externally, as is common in aquatic species, or internally, as is common in terrestrial species. Internal fertilization usually involves copulation. Hermaphroditic species have both male and female reproductive systems in the same individual, either sequentially or simultaneously. Internal fertilization is necessary for terrestrial species. The shelled egg is an important adaptation to the terrestrial environment, but it must be fertilized before the shell forms. All mammals except monotremes retain the embryo internally and have done away with shelled eggs. Animals can be classified as oviparous or viviparous, depending on whether the early stages of development occur outside or inside the mother's body. The Human Reproductive System Males produce semen and deliver it into the female reproductive tract. Semen consists of sperm suspended in a fluid that nourishes them and facilitates fertilization. Sperm are produced in the seminiferous tubules of the testes, mature in the epididymis, and are delivered to the urethra through the vasa deferentia. Other components of semen are produced in the bulbourethral gland, seminal vesicles, and prostate gland. Review Figures 43.8, 43.9 See Web/CD Activity 43.1 and 43.2 All components of the semen join in the urethra at the base of the penis and are ejaculated through the erect penis by muscle contractions at the culmination of copulation. Spermatogenesis depends on testosterone secreted by the Leydig cells of the testes, which are under the control of LH from the anterior pituitary. Spermatogenesis is also controlled by FSH from the pituitary. Hypothalamic GnRH controls pituitary secretion of LH and FSH. The production of these hormones by the hypothalamus and pituitary is controlled by negative feedback from testosterone and another hormone, inhibin, produced by the Sertoli cells of the testes. Review Figure 43.10 Eggs mature in the female's ovaries and are released into the oviducts. Sperm deposited in the vagina during copulation move up through the cervix and uterus into the oviducts. Review Figure 43.11 See Web/CD Activity 43.3 Fertilization occurs in the upper regions of the oviducts. The zygote becomes a blastocyst as it passes down the oviduct. Upon arrival in the uterus, the blastocyst implants in the endometrium and forms a placenta. The maturation and release of eggs constitute an ovarian cycle. In humans, this cycle takes about 28 days. Review Figures 43.12 The uterus also undergoes a cycle that prepares it for receipt of a blastocyst. If no blastocyst is implanted, the lining of the uterus deteriorates and sloughs off in the process of menstruation. Review Figure 43.13 See Web/CD Tutorial 43.2 Both the ovarian and the uterine cycles are under the control of hypothalamic and pituitary hormones, which in turn are under the feedback control of estrogen and progesterone. Review Figure 43.14 Childbirth is initiated by hormonal and mechanical stimuli that increase the contraction of uterine muscle. Oxytocin plays a major role in this positive feedback loop. Review Figure 43.15 Human Sexual Behavior Human sexual responses consist of four phases: excitement, plateau, orgasm, and resolution. In addition, males have a refractory period during which renewed excitement is not possible. Methods of contraception include abstention from copulation and the use of technologies that decrease the probability of fertilization. Review Table 43.1 Barrier methods of contraception, such as condoms, diaphragms, and spermicidal substances, kill sperm or block their passage through the

female reproductive tract. Methods to prevent ovulation, such as birth control pills and other hormonal treatments, interfere with the ovarian cycle so that mature, fertile eggs are not produced and released. Males and females can be sterilized by surgical blockage of the vasa deferentia (vasectomy) or oviducts (tubal ligation). Review Figure 43.16 Methods to prevent implantation include intrauterine devices, excess doses of steroids, and a progesterone receptor blocker. After implantation, the termination of a pregnancy is called an abortion. Assisted reproductive technologies have been developed to increase fertility. These ARTs include in vitro fertilization and gamete intrafallopian transfer. Many disease-causing organisms are transmitted through sexual behavior. Many sexually transmitted diseases are curable if treated early, but can have serious long-term consequences if not treated. Review Table 43.2 CHAPTER 44: NEURONS AND NERVOUS SYSTEMS Nervous Systems: Cells and Functions Nervous systems consist of cells called neurons that process and transmit information, along with supporting cells called glial cells. Sensory cells transduce information from the environment and the body. Neurons receive this information and transmit it to effectors such as muscles or glands. The nervous systems of different species vary, but all are composed of neurons. Review Figure 44.1 In vertebrates, the brain and spinal cord form the central nervous system, which communicates with the rest of the body via the peripheral nervous system. Neurons generally receive information via their dendrites and transmit information via their axons. Review Figure 44.2 Where neurons and their target cells meet, information is transmitted across synapses by the release of neurotransmitters. Glial cells physically support neurons and perform many housekeeping functions. Schwann cells and oligodendrocytes produce myelin, which insulates neurons. Astrocytes create the blood–brain barrier. Review Figure 44.3 Neurons work together in networks. Neurons: Generating and Conducting Nerve Impulses Neurons have an electric charge difference across their plasma membranes. This resting potential is created by ion pumps and ion channels. Review Figure 44.4 The sodium-potassium pump concentrates K+ on the inside of a neuron and Na+ on the outside. Potassium channels allow K+ to diffuse out of the neuron, leaving behind unbalanced negative charges. Review Figures 44.5, 44.6 See Web/CD Tutorial 44.1 A potassium equilibrium potential exists when the tendency of K+ ions to diffuse out of the neuron is balanced by the negative charges pulling them back in. This potential can be calculated using the Nernst equation. Review Figure 44.7 The resting potential is perturbed when ion channels open or close, changing the permeability of the plasma membrane to charged ions. Through this mechanism, the plasma membrane can become depolarized or hyperpolarized. Review Figure 44.8 An action potential is a rapid reversal in charge across a portion of the plasma membrane resulting from the sequential opening and closing of voltage-gated sodium and potassium channels. These changes in voltage-gated channels occur when the plasma membrane depolarizes to a threshold level. Review Figure 44.9 See Web/CD Tutorial 44.2 Action potentials are all-or-nothing, self-regenerating events. They are conducted down axons because local current flow depolarizes adjacent regions of membrane and brings them to threshold. Review Figure 44.10 Patch clamping allows the study of single ion channels. Review Figure 44.11 In myelinated axons, action potentials appear to jump between nodes of Ranvier, patches of axonal plasma membrane that are not covered by myelin. Review Figure 44.12 Neurons, Synapses, and Communication Neurons communicate with each

other and with other cells at specialized junctions called synapses, where the plasma membranes of two cells come close together. The classic chemical synapse is the neuromuscular junction, a synapse between a motor neuron and a muscle cell. Its neurotransmitter is acetylcholine, which causes a depolarization of the postsynaptic membrane when it binds to its receptor. Review Figure 44.13 See Web/CD Tutorial 44.3 When a nerve impulse reaches an axon terminal, it causes the release of neurotransmitters, which diffuse across the synaptic cleft and bind to receptors on the postsynaptic membrane. Review Figures 44.13, 44.14 Synapses between neurons can be either excitatory or inhibitory. A postsynaptic neuron integrates information by summing excitatory and inhibitory postsynaptic potentials in both space and time. Review Figure 44.15 Synapses that form between the axon terminals of one neuron and another can influence the release of neurotransmitter by the second cell by presynaptic excitation or presynaptic inhibition. Ionotropic receptors are ion channels. Metabotropic receptors are G protein-linked receptors that influence the postsynaptic cell through various signal transduction pathways and result in the opening of ion channels. The actions of ionotropic synapses are generally faster than those of metabotropic synapses. Review Figure 44.16 Electrical synapses allow electric signals to pass between cells without the use of neurotransmitters. There are many different neurotransmitters and even more types of receptors. The action of a neurotransmitter depends on the receptor to which it binds. Review Table 44.1 See Web/CD Activity 44.1 With repeated stimulation, a neuron can become more sensitive to its inputs. Since this increased sensitivity can last a long time, it is called long-term potentiation, or LTP. The properties of the NMDA glutamate receptor appear to explain LTP. Review Figure 44.18 In chemical synapses, the transmitter must be cleared rapidly from the synapse. Some poisons and drugs act by blocking or slowing the clearance of transmitter from the synapse.

CHAPTER 45: SENSORY SYSTEMS Sensory Cells and Transduction of Stimuli Sensory cells transduce information about an animal's external and internal environment into action potentials. The interpretation of action potentials as particular sensations depends on which neurons in the CNS receive them. Sensory cells have membrane receptor proteins that cause ion channels to open or close, generating receptor potentials. Review Figures 45.1, 45.14 Receptor potentials can spread to regions of the sensory cell plasma membrane that generate action potentials, or they can influence the release of neurotransmitters from the sensory cell. Review Figure 45.2 Adaptation enables the nervous system to ignore irrelevant or continuous stimuli while remaining responsive to relevant or new stimuli. Chemoreceptors: Responding to Specific Molecules Chemoreceptors are responsible for smell, taste, and the sensing of pheromones. Olfactory sensory cells contain receptor proteins that can bind a specific molecule or ion. The binding of an odorant molecule to a receptor protein causes the production of a second messenger, which opens ion channels and creates an action potential in the sensory cell. Review Figure 45.4 Taste buds in the mouth cavities of vertebrates are responsible for the sense of gustation. Review Figure 45.5 Mechanoreceptors: Detecting Stimuli that Distort Membranes The skin contains a variety of mechanoreceptors that

respond to touch and pressure. The density of mechanoreceptors in any skin area determines the sensitivity of that area. Review Figure 45.6 Stretch receptors in muscles, tendons, and ligaments inform the CNS of the positions of and loads on parts of the body. Review Figure 45.7 Hair cells are also mechanoreceptors. The bending of their stereocilia alters receptor proteins and therefore their membrane potentials. Hair cells are found in the auditory organs and organs of equilibrium such as the lateral line system of fishes and the semicircular canals and vestibular apparatus of mammals. Review Figures 45.8, 45.9 In mammalian auditory systems, ear pinnae collect and direct sound waves to the tympanic membrane, which vibrates in response to sound waves. The movements of the tympanic membrane are amplified through a chain of ossicles that conduct the vibrations to the oval window. Movements of the oval window create pressure waves in the fluid-filled cochlea. Review Figure 45.10 See Web/CD Activity 45.1 and Tutorial 45.1 The basilar membrane running down the center of the cochlea is distorted by sound waves at specific locations that depend on their frequency. These distortions cause the bending of hair cells in the organ of Corti, which rests on the basilar membrane. Receptor potentials in hair cells cause them to release neurotransmitter, which creates action potentials in the auditory nerve, which conducts the information to the CNS. Review Figure 45.11 Photoreceptors and Visual Systems: Responding to Light Photosensitivity depends on the absorption of photons of light by rhodopsin, a photoreceptor molecule that consists of a protein called opsin and a light-absorbing prosthetic group called retinal. Absorption of light by retinal is the first step in a cascade of intracellular events leading to a change in the membrane potential of the photoreceptor cell. Review Figure 45.12 When excited by light, vertebrate photoreceptor cells hyperpolarize and release less neurotransmitter onto the neurons with which they form synapses. They do not fire action potentials. Review Figures 45.13, 45.14 Visual systems vary from the simple eye cups of flatworms, which enable the animal to sense the direction of a light source, to the compound eyes of arthropods, which enable the animal to detect shapes and patterns, to the image-forming eyes of cephalopods and vertebrates. Review Figures 45.15, 45.16 See Web/CD Activity 45.2 The image-forming eyes of vertebrates focus detailed images of the visual field onto dense arrays of photoreceptors that transduce the visual image into neuronal signals. Review Figure 45.17 Vertebrates have two types of photoreceptors, rod cells and cone cells. In humans, the fovea contains almost exclusively cone cells, which are responsible for color vision but are not very sensitive in dim light. Color vision is based on the fact that different cone cells contain different isomers of opsin, which give them different spectral absorption properties. Review Figure 45.19 The vertebrate retina consists of five layers of neurons lining the back of the eye. The light-absorbing photoreceptor cells are at the back of the retina. Review Figure 45.20 See Web/CD Activity 45.3 The innermost layer of the retina consists of the ganglion cells, which send their axons in the optic nerve to the brain. Between the photoreceptors and the ganglion cells are neurons that process information from the photoreceptors. Each ganglion cell is stimulated by light falling on a small circular patch of photoreceptors called a receptive field. Receptive fields have a center and a surround, which have opposing effects on the ganglion cell. If the center is excitatory, the surround is inhibitory, and vice versa. Review Figure 45.21 See Web/CD Tutorial 45.2 Sensory Worlds beyond Human

Experience Many animals have sensory abilities that humans do not share. Insects see ultraviolet radiation, pit vipers "see" infrared radiation, elephants communicate with low-frequency sound, bats echolocate, and some fishes sense electric fields. CHAPTER 46: THE MAMMALIAN NERVOUS SYSTEM: STRUCTURE AND HIGHER FUNCTIONS The Nervous System: Structure, Function, and Information Flow The brain and spinal cord make up the central nervous system; the cranial and spinal nerves make up the peripheral nervous system. A nerve is a bundle of many axons carrying information to and from the central nervous system. The nervous system can be modeled conceptually in terms of the direction of information flow and whether or not we are conscious of the information. Review Figure 46.1 The vertebrate nervous system develops from a hollow dorsal neural tube. The brain forms from three swellings at the anterior end of the neural tube, which become the hindbrain, the midbrain, and the forebrain. Review Figure 46.2 The forebrain develops into the cerebral hemispheres (the telencephalon) and the underlying thalamus and hypothalamus (the diencephalon). The midbrain and hindbrain develop into the brain stem. Functional Subsystems of the Nervous System The nervous system is composed of many subsystems that function simultaneously. Some important subsystems are the spinal cord, the reticular system, the limbic system, and the cerebrum. The spinal cord communicates information between the brain and the rest of the body. It also processes and integrates much information, and can issue some commands to the body without input from the brain. Review Figure 46.3 See Web/CD Tutorial 46.1 The reticular system is a complex network that directs incoming information to appropriate brain stem nuclei that control autonomic functions, as well as transmitting the information to the forebrain that results in conscious sensation. The reticular system controls the level of arousal of the nervous system. The limbic system is an evolutionarily primitive part of the telencephalon that is involved in emotions, physiological drives, instincts, and memory. Review Figure 46.4 The cerebral hemispheres are the dominant structures of the human brain. Their surfaces consist of a layer of neurons called the cerebral cortex. Most of the cerebral cortex is involved in higher-order information processing; these areas are generally called association cortex. The cerebral hemispheres can be divided into temporal, frontal, parietal, and occipital lobes. Many motor functions are localized in parts of the frontal lobe. Information from many sensory receptors around the body projects to a region of the parietal lobe. Visual information projects to the occipital lobe, and auditory information projects to a region of the temporal lobe. Review Figures 46.5, 46.6, 46.7 See Web/CD Activity 46.1 Information Processing by Neuronal Networks The functions of the nervous system are beginning to be understood in terms of the properties of cells organized in neuronal networks. The autonomic nervous system consists of efferent pathways that control the physiological function of organs and organ systems. Its sympathetic and parasympathetic divisions normally work in opposition to each other. These divisions are characterized by their anatomy, neurotransmitters, and effects on target tissues. Review Figure 46.10 Neuronal circuits in the occipital cortex integrate visual information. Information from the receptive fields of retinal ganglion cells is communicated to the brain in the optic nerves. This information is transmitted to the visual cortex in such a way as to create receptive fields for cortical cells. A simple cell in the visual cortex is stimulated by a bar of light with a specific orientation falling at a

specific location on the retina. A complex cell is maximally stimulated by such a stimulus moving across the retina. The visual cortex seems to assemble a mental image of the visual world by analyzing edges of patterns of light. Review Figure 46.11 Binocular vision results from circuits that communicate information from both eyes to binocular cells in the visual cortex. These cells interpret distance by measuring the disparity between where the same stimulus falls on the two retinas. Review Figure 46.12 Understanding Higher Brain Functions in Cellular Terms Humans have a daily cycle of sleep and waking. Sleep can be divided into slow-wave (non-REM) sleep and rapid-eye-movement (REM) sleep. Human non-REM sleep is divided into four stages of increasing depth. Review Figure 46.13 Some learning and memory processes have been localized to specific brain areas. Repeated activation of identified circuits in the hippocampus has revealed long-lasting changes in synaptic properties referred to as long-term potentiation and long-term depression, which may be involved in learning and memory. Review Figure 46.14 Complex memories can be elicited by stimulating small regions of association cortex. Damage to the hippocampus can destroy the ability to form long-term declarative memories, but not procedural memories. Language abilities are localized mostly in the left cerebral hemisphere, a phenomenon known as lateralization. Different areas of the left hemisphere—including Broca's area, Wernicke's area, and the angular gyrus—are responsible for different aspects of language. Review Figure 46.15 See Web/CD Activity 46.2 See Web/CD Activity 46.3 for a concept review of this chapter. CHAPTER 47: EFFECTORS: MAKING ANIMALS MOVE Effectors enable animals to respond to information from their internal and external environments. Most effectors generate mechanical forces and cause movement. Microtubules, Microfilaments, and Cell Movement Cell movement is generated by two components of the cytoplasmic skeleton, microtubules and microfilaments, both of which consist of long protein molecules that can change their length or shape. The movements of cilia and flagella depend on microtubules. Microfilaments allow animal cells to change their shape and move. Muscle Contraction The three types of vertebrate muscle are smooth, cardiac, and skeletal (striated). Review Figure 47.1 Smooth muscle provides contractile force for internal organs. Smooth muscle cells are electrically connected by gap junctions, so action potentials can spread rapidly throughout smooth muscle tissue. Smooth muscle cells are sensitive to stretching and to neurotransmitters from the autonomic nervous system. Review Figure 47.2 See Web/CD Tutorial 47.2 The walls of the heart consist of sheets of branching cardiac muscle cells. The cells are electrically connected by gap junctions, so that action potentials spread rapidly throughout sheets of cardiac muscle and cause coordinated contractions. Some cardiac muscle cells are pacemaker cells that generate the heartbeat. Skeletal, or striated, muscle consists of bundles of muscle fibers. Each muscle fiber is a huge cell containing multiple nuclei. Skeletal muscles contain numerous myofibrils, which are bundles of actin and myosin filaments. The regular, overlapping arrangement of the actin and myosin filaments into sarcomeres gives skeletal muscle its striated appearance. During contraction, the actin and myosin filaments slide past each other in a telescoping fashion. Review Figure 47.3 See Web/CD Activity 47.1 The molecular mechanism of muscle contraction involves the binding of the globular heads of myosin molecules to actin. Upon binding, the myosin head changes its conformation, causing the two filaments to slide past each other. Release of the myosin heads from

actin and their return to their original conformation requires ATP. Review Figure 47.4 The plasma membrane of the muscle fiber is continuous with a system of T tubules that extends deep into the sarcoplasm. Review Figure 47.5 See Web/CD Activity 47.2 When an action potential spreads across the plasma membrane and through the T tubules, it causes Ca2+ ions to be released from the sarcoplasmic reticulum. The Ca2+ ions bind to troponin and change its conformation, pulling the tropomyosin strands away from the myosin binding sites on the actin filament. Cycles of actin-myosin binding and release occur, and the muscle fiber contracts until the Ca2+ is returned to the sarcoplasmic reticulum. Review Figure 47.6 In skeletal muscle, a single action potential causes a minimum unit of contraction called a twitch. Twitches occurring in rapid succession can be summed, thus increasing the strength of contraction. Review Figure 47.7 See Web/CD Tutorial 47.1 Muscle Strength and Performance Slow-twitch muscle fibers are adapted for extended, aerobic work; fast-twitch fibers are adapted for generating maximum forces for short periods of time. The ratio of slow-twitch to fast-twitch fibers in the muscles of an individual is genetically determined. Review Figure 47.8 The force that a muscle fiber can produce depends on its initial state of extension or contraction. Review Figure 47.9 Anaerobic exercise stimulates the enlargement of muscle fibers through production of new microfilaments. Through aerobic conditioning, muscle fibers can acquire greater oxidative capacity. Muscle performance depends on fuel supply. Available ATP and creatinine phosphate can fuel maximum tension immediately, but are exhausted in seconds. Glycolysis can regenerate ATP rapidly, but is rapidly slowed by accumulation of lactic acid. Oxidative metabolism delivers ATP more slowly, but can continue to do so for a long time. Review Figure 47.10 Skeletal Systems Skeletal systems provide rigid supports against which muscles can pull. Hydrostatic skeletons are fluid-filled body cavities that can be squeezed by muscles. Review Figure 47.11 Exoskeletons are hardened outer surfaces to which internal muscles are attached. Endoskeletons are internal systems of rigid rodlike, platelike, and tubelike supports, consisting of bone and cartilage, to which muscles are attached. Review Figure 47.12 Bone is continually being remodeled by osteoblasts, which lay down new bone, and osteoclasts, which erode bone. Review Figure 47.13 Bones develop from connective tissue membranes (membranous bone) or from cartilage through ossification (cartilage bone). Cartilage bone can grow until centers of ossification meet. Review Figure 47.14 Bone can be solid and hard (compact bone), or it can contain numerous internal spaces (cancellous bone). Most of the compact bone of mammals is composed of Haversian systems. Review Figure 47.15 Tendons connect muscles to bones; ligaments connect bones to one another. Review Figure 47.16 Muscles and bones work together around joints as systems of levers. Review Figures 47.17, 47.18 See Web/CD Activity 47.3 Other Effectors Effector organs other than muscles include nematocysts, chromatophores, glands, and electric organs. Review Figure 47.19 CHAPTER 48: GAS EXCHANGE IN ANIMALS Physical Processes of Respiratory Gas Exchange Most cells require a constant supply of O_2 and continuous removal of CO_2. These respiratory gases are exchanged between the body fluids of an animal and its environment by diffusion. In aquatic animals, gas exchange is limited by the low diffusion rate and low amount of O_2 in water. Aquatic animals face a double bind in that the amount of O_2 in water decreases, but their metabolism and the amount of work required to move water over their gas exchange surfaces increase, as water

temperature rises. Review Figure 48.2 In air, the partial pressure of oxygen decreases with altitude. Fick's law of diffusion shows how various physical factors influence the rate of diffusion of gases. Adaptations to maximize respiratory gas exchange influence one or more components of Fick's law. Adaptations for Respiratory Gas Exchange Adaptations to maximize gas exchange include increasing the surface areas for gas exchange, maximizing partial pressure gradients across those exchange surfaces by decreasing their thickness, ventilating the outer surface with the respiratory medium, and perfusing the inner surface with blood. Review Figure 48.3 Insects distribute air throughout their bodies in a system of tracheae, tracheoles, and air capillaries. Review Figure 48.4 Fish have large gas exchange surface areas that are ventilated continuously and unidirectionally with water. Countercurrent blood flow helps increase the efficiency of gas exchange. Review Figures 48.5, 48.6 The gas exchange system of birds includes air sacs that communicate with the lungs, but are not used for gas exchange. Air flows unidirectionally through bird lungs in parabronchi. Gases are exchanged in air capillaries that run between parabronchi. Review Figure 48.7 Each breath of air remains in the bird respiratory system for two breathing cycles. The air sacs work as bellows to supply the air capillaries with a continuous, unidirectional flow of fresh air. Review Figure 48.8 See Web/CD Tutorial 48.1 Breathing in vertebrates other than birds is tidal and is therefore less efficient than gas exchange in fish or birds. Even though the volume of air exchanged with each breath can vary considerably, the inhaled air is always mixed with stale air. Review Figure 48.9 Gas Exchange in Human Lungs In mammalian lungs, the gas exchange surface area provided by the millions of alveoli is enormous, and the diffusion path length between the air and perfusing blood is very short. Review Figure 48.10 See Web/CD Activity 48.1 Surface tension in the alveoli would make inflation of the lungs difficult if the alveoli did not produce surfactant. Inhalation occurs when contractions of the diaphragm create subatmospheric pressure in the thoracic cavity. Relaxation of the diaphragm increases pressure in the thoracic cavity and causes exhalation. Review Figure 48.11 See Web/CD Tutorial 48.2 During periods of heavy metabolic demands, such as strenuous exercise, the intercostal muscles, located between the ribs, increase the volume of air inhaled and exhaled. Blood Transport of Respiratory Gases Oxygen is reversibly bound to hemoglobin in red blood cells. Each molecule of hemoglobin can carry a maximum of four molecules of O_2. Because of positive cooperativity, the affinity of hemoglobin for O_2 depends on the PO_2 to which the hemoglobin is exposed. Therefore, hemoglobin picks up O_2 as it flows through respiratory exchange structures and gives up O_2 in metabolically active tissues. Review Figure 48.12 Myoglobin has a high affinity for O_2 and serves as an O_2 reserve in muscle. There is more than one type of hemoglobin. Fetal hemoglobin has a higher affinity for O_2 than does maternal hemoglobin, allowing fetal blood to pick up O_2 from the maternal blood in the placenta. Review Figure 48.13 The affinity of hemoglobin for O_2 is decreased by the presence of hydrogen ions or 2,3 bisphosphoglyceric acid. Carbon dioxide is transported in the blood principally as bicarbonate ions. Review Figure 48.14 See Web/CD Activity 48.2 Regulation of Breathing The breathing rhythm is an autonomic function generated by neurons in the medulla and modulated by higher brain centers. Review Figure 48.15 The most important feedback stimulus for breathing is the level of CO_2 in the blood. Review Figure 48.16 The breathing rhythm is sensitive to feedback

from chemoreceptors on the ventral surface of the medulla and in the carotid and aortic bodies on the large vessels leaving the heart. Review Figure 48.17 See Web/CD Activity 48.3 for a concept review of this chapter.

CHAPTER 49: CIRCULATORY SYSTEMS Circulatory Systems: Pumps, Vessels, and Blood The metabolic needs of the cells of small aquatic animals are met by direct exchange of materials with the external medium. The metabolic needs of the cells of larger animals are met by a circulatory system that transports nutrients, respiratory gases, and metabolic wastes throughout the body. In open circulatory systems, the blood or tissue fluid leaves vessels and percolates through tissues. Review Figure 49.1 In closed circulatory systems, the blood is contained in a system of vessels. Review Figure 49.2 Vertebrate Circulatory Systems The circulatory systems of vertebrates consist of a heart and a closed system of vessels containing blood that is separate from the tissue fluid. Arteries and arterioles carry blood from the heart; capillaries are the site of exchange between blood and tissue fluid; venules and veins carry blood back to the heart. The vertebrate heart evolved from two chambers in fishes to three in amphibians and reptiles and four in crocodilians, mammals, and birds. This evolutionary progression has led to an increasing separation of blood that flows to the gas exchange organs and blood that flows to the rest of the body. Review Pages 943-945. See Web/CD Activity 49.1 In birds and mammals, blood circulates through two circuits: the pulmonary circuit and the systemic circuit. The Human Heart: Two Pumps in One The human heart has four chambers. Valves in the heart prevent the backflow of blood. Review Figure 49.3 See Web/CD Activity 49.2 The cardiac cycle has two phases: systole, in which the ventricles contract; and diastole, in which the ventricles relax. The sequential heart sounds ("lub-dub") are made by the closing of the heart valves. Review Figure 49.4 See Web/CD Tutorial 49.1 Blood pressure can be measured using a sphygmomanometer and a stethoscope. Review Figure 49.5 The autonomic nervous system controls heart rate: Sympathetic activity increases heart rate, and parasympathetic activity decreases it. These actions are due to the effects of norepinephrine and acetylcholine on the rate of depolarization of the plasma membranes of pacemaker cells. Review Figure 49.6 The sinoatrial node controls the cardiac cycle by initiating a wave of depolarization in the atria, which is conducted to the ventricles through a system consisting of the atrioventricular node, the bundle of His, and the Purkinje fibers. Review Figure 49.7 The sustained contraction of ventricular muscle cells is due to long action potentials that are generated by voltage-gated calcium channels. Review Figure 49.8 An EKG records electrical events associated with the contraction and relaxation of the cardiac muscles. Review Figure 49.9 The Vascular System: Arteries, Capillaries, and Veins Arteries and arterioles have many elastic fibers that enable them to withstand high pressures. Abundant smooth muscle cells allow these vessels to change their diameter, altering their resistance and thus blood flow. Review Figure 49.10 See Web/CD Activity 49.3 Capillary beds are the site of exchange of materials between blood and tissue fluid. The Starling hypothesis offers

an explanation for the exchange of fluids between blood and tissues that is based on the balance between blood pressure and osmotic pressure in the capillaries. Review Figure 49.12 The ability of a specific molecule to cross a capillary wall depends on the architecture of the capillary, the type of substance, and the concentration gradient between the blood and the tissue fluid. Veins have a high capacity for storing blood. Aided by gravity, by contractions of skeletal muscle, and by the actions of breathing, they return blood to the heart. Review Figure 49.13 The lymphatic system returns the tissue fluid to the blood. Cardiovascular disease is responsible for about half of all deaths in the United States and Europe. Blood: A Fluid Tissue Blood can be divided into a plasma portion (water, salts, and proteins) and a cellular portion (red blood cells, white blood cells, and platelets). All of the cellular components are produced from stem cells in the bone marrow. Review Figure 49.15 Red blood cells transport respiratory gases. Their production in the bone marrow is stimulated by erythropoietin, which is produced in response to hypoxia in the tissues. Platelets, along with circulating proteins, are involved in blood clotting. Review Figure 49.16 Plasma is a complex solution that contains gases, ions, nutrient molecules, proteins, and other molecules. Control and Regulation of Circulation Blood flow through capillary beds is controlled by local autoregulatory mechanisms, hormones, and the autonomic nervous system. Review Figure 49.17 Blood pressure is controlled in part by the hormones vasopressin and angiotensin, which stimulate contraction of blood vessels. Review Figure 49.18 Heart rate is controlled by the autonomic nervous system, which responds to information about blood pressure and blood composition that is integrated by regulatory centers in the medulla. Review Figure 49.19 Diving mammals conserve blood oxygen stores by slowing the heart rate during dives. Review Figure 49.20 CHAPTER 50: NUTRITION, DIGESTION, AND ABSORPTION Nutrient Requirements Animals are heterotrophs that derive their energy and molecular building blocks, directly or indirectly, from autotrophs. Carbohydrates, fats, and proteins in food supply animals with metabolic energy. A measure of the energy content of food is the calorie. Excess caloric intake is stored as glycogen and fat. Review Figure 50.2 An animal with insufficient caloric intake is undernourished and must metabolize its stored glycogen and fat, and finally its own proteins, for energy. In humans, overnutrition can also be a serious health hazard. Review Figure 50.3 For many animals, food provides essential carbon skeletons that they cannot synthesize themselves. Review Figure 50.4 Humans require eight essential amino acids in the diet. All are available in milk, eggs, or meat, but not in all vegetables. Thus, vegetarians must eat a mix of complementary foods. Review Figure 50.5 Different animals need mineral elements in different amounts. Macronutrients, such as calcium, are needed in large quantities. Micronutrients, such as iron, are needed in small amounts. Review Table 50.1 See Web/CD Activity 50.1 Vitamins are organic molecules that must be obtained in food. Review Table 50.2 See Web/CD Activity 50.2 Malnutrition results when any essential nutrient is lacking from the diet. A chronic state of malnutrition causes a deficiency disease. Adaptations for Feeding Animals can be characterized by how they acquire nutrients: Saprotrophs and detritivores depend on dead organic matter, filter feeders strain the aquatic environment for small food items, herbivores eat plants, and carnivores eat animals. Behavioral and anatomical adaptations reflect feeding strategies. In vertebrates, teeth have evolved to match the diet.

Review Figure 50.7 See Web/CD Activity 50.3 Digestion Digestion involves the breakdown of complex food molecules into monomers that can be absorbed and utilized by cells. In most animals, digestion is extracellular and external to the body, taking place in a tubular gut that has different regions specialized for different digestive functions. Review Figure 50.8 Absorptive areas of the gut are characterized by a large surface area. Review Figure 50.9 Hydrolytic enzymes break down proteins, carbohydrates, and fats into their monomeric units. To prevent the organism itself from being digested, these enzymes are released as inactive zymogens, which become activated when secreted into the gut. Structure and Function of the Vertebrate Gut The vertebrate gut can be divided into several compartments with different functions. Review Figure 50.10 See Web/CD Activity 50.4 The cells and tissues of the vertebrate gut are organized in the same way throughout its length. The innermost tissue layer, the mucosa, is the secretory and absorptive surface. The submucosa contains secretory cells and glands, blood and lymph vessels and nerves. External to the submucosa are two smooth muscle layers (circular and longitudinal) that move food through the gut. Between the two muscle layers is a nerve network that controls the movements of the gut. Review Figure 50.11 Swallowing is a reflex that pushes food into the esophagus. Peristalsis moves food from the beginning of the esophagus through the entire length of the gut. Sphincters block the gut at certain locations, but they relax as a wave of peristalsis approaches. Review Figure 50.12 Enzymatic digestion begins in the mouth, where amylase is secreted with the saliva. Protein digestion begins in the stomach, where pepsin and HCl are secreted by the stomach mucosa. The mucosa also secretes mucus, which protects the tissues of the gut. Review Figures 50.13, 50.14 In the duodenum, pancreatic enzymes carry out most of the digestion of food. Bile from the liver and gallbladder assists in the digestion of fats by breaking them into micelles. Bicarbonate ions from the pancreas neutralize the pH of the chyme entering from the stomach to produce an environment conducive to the actions of pancreatic enzymes. Review Figure 50.15, Table 50.3 Final enzymatic cleavage of polypeptides and disaccharides occurs among the microvilli of the intestinal mucosa. Amino acids, monosaccharides, and many inorganic ions are absorbed by the microvilli. In many cases, specific transporter proteins in the plasma membranes of the mucosal cells transport nutrients into the cells. Sodium cotransport is a common mechanism for actively absorbing nutrient molecules and ions. Fats are broken down by lipases and absorbed mostly as monoglycerides and fatty acids. These products pass through the membranes of mucosal cells and are then resynthesized into triglycerides within the cells. The triglycerides are combined with cholesterol and phospholipids and coated with protein to form chylomicrons, which pass out of the mucosal cells and into lymphatic vessels in the submucosa. Review Figure 50.16b See Web/CD Tutorial 50.1 Water and ions are absorbed in the large intestine as waste matter is consolidated into feces, which are periodically excreted. In herbivores such as ruminants and rabbits, some compartments of the gut have large populations of microorganisms that aid in digesting materials that otherwise would be indigestible to their host. Review Figure 50.17 Control and Regulation of Digestion Autonomic reflexes coordinate activity in different regions of the digestive tract, which has an intrinsic nervous system that can act independently of the CNS. The actions of the stomach and small intestine are largely controlled by the hormones gastrin, secretin, and

cholecystokinin. Review Figure 50.18 Control and Regulation of Fuel Metabolism The liver plays a central role in directing the traffic of fuel molecules. During the absorptive period, the liver takes up and stores fats and carbohydrates, converting monosaccharides to glycogen or fats. The liver also takes up amino acids and uses them to produce blood plasma proteins. Fat and cholesterol are shipped out of the liver as low-density lipoproteins. High-density lipoproteins act as acceptors of cholesterol and are believed to bring fat and cholesterol back to the liver. Fuel metabolism during the absorptive period is controlled largely by insulin, which promotes glucose uptake and utilization by most cells of the body, as well as glycogen and fat synthesis. During the postabsorptive period, the lack of insulin blocks the uptake and utilization of glucose by most cells of the body except neurons. If blood glucose levels fall, glucagon is secreted, stimulating the liver to break down glycogen and release glucose to the blood. Review Figures 50.17, 50.19 See Web/CD Tutorial 50.2 The Regulation of Food Intake Food intake is governed by sensations of hunger and satiety, which are determined by brain mechanisms. Leptin is a hormone produced by fat cells that inhibits food intake, apparently by providing feedback information about fat reserves to the brain. Toxic Compounds in Food Natural plant and animal foods can contain toxic compounds in addition to nutrients. Human activities such as the use of pesticides and the release of pollutants into the environment have made the problem of toxins in food even worse. An organism can accumulate toxic compounds in its body, especially if those compounds are lipid-soluble or take the structural place of a natural molecule. Toxins such as PCBs that accumulate in the bodies of prey are transferred to and further concentrated in the bodies of their predators. This bioaccumulation produces high concentrations of toxins in animals high up the food chain. CHAPTER 51: SALT AND WATER BALANCE AND NITROGEN EXCRETION Tissue Fluid and Water Balance Most adaptations for maintaining salt and water balance and for excreting nitrogen wastes employ the same basic mechanisms: filtration of tissue fluid and active secretion and resorption of specific molecules. The problems of salt and water balance and nitrogen excretion that animals face depend on their environments, but in all animal excretory systems, there is no active transport of water. Marine animals can be osmoconformers or osmoregulators. Freshwater animals must be osmoregulators and must continually excrete water and conserve salts. Most animals are ionic regulators to some degree. Review Figure 51.1 On land, water conservation is essential, and diet determines whether salts must be conserved or excreted. Marine birds excrete excess salt through nasal salt glands. Review Figure 51.2 Excreting Nitrogenous Wastes Aquatic animals can eliminate nitrogenous wastes such as ammonia by diffusion across their gill membranes. Terrestrial animals must detoxify ammonia by converting it to urea or uric acid before excretion. Review Figure 51.3 Depending on the form in which they excrete their nitrogenous wastes, animals are classified as ammonotelic, ureotelic, or uricotelic. The Diverse Excretory Systems of Invertebrates The protonephridia of flatworms consist of flame cells and excretory tubules. Tissue fluid is filtered into the tubules, which process the filtrate to produce a dilute urine. Review Figure 51.4 In annelid worms, blood pressure causes filtration of the blood across capillary walls. The filtrate enters the coelomic cavity, where it is taken up by metanephridia. As the filtrate passes through the metanephridia to the outside, its composition is changed by

active transport mechanisms. Review Figure 51.5 See Web/CD Activity 51.1 The Malpighian tubules of insects receive ions and nitrogenous wastes by active transport across the tubule cells. Water follows by osmosis. Ions and water are resorbed from the rectum, so the insect excretes semisolid wastes. Review Figure 51.6 Vertebrate Excretory Systems The nephron, the functional unit of the vertebrate kidney, consists of a glomerulus, in which blood is filtered across the walls of a knot of capillaries, a renal tubule, which processes the filtrate into urine to be excreted, and a system of peritubular capillaries, which surround the tubule. Review Figure 51.7 See Web/CD Activity 51.2 The adaptations of marine and terrestrial animals for conserving water are diverse. Marine bony fishes have few glomeruli and produce little urine. Cartilaginous fishes retain urea so that the osmolarity of their body fluids remains close to that of seawater. Amphibians remain close to water or have waxy skin coverings. Reptiles have scaly skin, lay shelled eggs, and excrete nitrogenous wastes as uric acid. Birds share the adaptations of reptiles; in addition, they can produce urine more concentrated than their tissue fluid. Only birds and mammals can produce such hypertonic urine. The Mammalian Excretory System The concentrating ability of the mammalian kidney depends on its anatomy. Review Figure 51.9a, 51.9b The glomeruli and the proximal and distal convoluted tubules are located in the cortex of the kidney. Certain molecules are actively resorbed from the glomerular filtrate by the tubule cells, and other molecules are actively secreted. Straight sections of renal tubules called loops of Henle and collecting ducts are arranged in parallel in the medulla of the kidney. Review Figure 51.9c See Web/CD Activity 51.3 Salts and water are resorbed in the proximal convoluted tubule without the renal filtrate becoming more concentrated, although its composition changes. The loops of Henle create a concentration gradient in the tissue fluid of the renal medulla by a countercurrent multiplier mechanism. Urine flowing down the collecting ducts to the ureter is concentrated by the osmotic resorption of water caused by the concentration gradient in the surrounding tissue fluid. Review Figure 51.10 Hydrogen ions secreted by the renal tubules are buffered in the urine by bicarbonate and other chemical buffering systems. Review Figure 51.12 See Web/CD Tutorial 51.1 Regulation of Kidney Functions Kidney function in mammals is controlled by autoregulatory mechanisms that maintain a constant high glomerular filtration rate even if blood pressure varies. An important autoregulatory mechanism is the release of renin by the kidney when blood pressure falls. Renin activates angiotensin, which causes the constriction of peripheral blood vessels, causes the release of aldosterone (which enhances water resorption), and stimulates thirst. Changes in blood pressure and osmolarity influence the release of antidiuretic hormone, which controls the permeability of the collecting duct to water and therefore the amount of water that is resorbed from the urine. ADH stimulates the expression of proteins called aquaporins that serve as water channels in the membranes of collecting duct cells. Review Figure 51.13 When the volume of blood returning to the heart increases and stretches the atrial walls, they release atrial natriuretic peptide (ANP), which causes increased excretion of salt and water. CHAPTER 52: ANIMAL BEHAVIOR What, How, and Why Questions Studies of animal behavior seek to describe behavior, understand its mechanisms, and understand its evolution. Behavior Shaped by Inheritance Many behaviors of many species are stereotypic and species-specific, and are thus largely determined by

inheritance. They do not require experience and are minimally modifiable by learning. Deprivation experiments deprive an animal of opportunities to learn a behavior and can therefore reveal that a behavior is inherited. Hybridization experiments can also reveal genetic influences on behavior. Review Figure 52.2 Some behaviors are triggered by simple stimuli called releasers. Review Figure 52.3 Spatial learning enables an animal to learn and use information about its physical environment. Review Figure 52.4 Imprinting enables an animal to learn the features of a complex releaser, such as the identity of its parents. The acquisition of bird song is an example in which inheritance and learning interact, enabling an animal to learn a behavior if exposed to the correct stimuli during certain critical periods. Review Figure 52.6 Genetically programmed behavior is highly adaptive for species, such as those with nonoverlapping generations, that have little opportunity to learn, for species that might learn the wrong behavior, and in situations in which mistakes are costly or dangerous. Hormones and Behavior In rats, the sex steroids present during development determine what sexual behavior patterns develop, and the sex steroids present in the adult control the expression of those patterns. Review Figure 52.7 See Web/CD Tutorial 52.1 In birds, testosterone determines a bird's ability to sing by causing the brain regions responsible for song to develop. Review Figure 52.8 The Genetics of Behavior There are many complex steps between the expression of a gene as a protein product and the expression of a behavior. Several types of experiments help reveal how genes affect behavior. Artificial selection and crossbreeding can produce individuals with particular behavioral traits that are inherited. Review Figure 52.9 The techniques of molecular genetics can reveal the functions of specific genes that influence behavior. Review Figure 52.10 Communication Communication consists of displays or signals that can be perceived by other individuals and which influence their behavior. Natural selection favors communication systems when both sender and receiver benefit from the exchange of information. Many animals communicate by emitting pheromones into the environment and by sensing the pheromones of other animals. Pheromonal messages can last a long time, but they cannot be changed quickly. Visual communication is easy, versatile, and rapid, but it is limited by its directionality, by the visual acuity of the receiver, and by environmental conditions such as darkness. Auditory signals can be used at night, can go around objects that would interfere with visual communication, can easily get the receiver's attention, can provide directional information, and can travel long distances. Tactile signals can communicate complex messages, as the dance of the honeybee demonstrates. Review Figure 52.12 See Web/CD Activity 52.1 The electric signals generated by some fishes can be used for communication. The Timing of Behavior: Biological Rhythms Animal behavior is expressed in daily cycles called circadian rhythms. A circadian rhythm is an endogenous rhythm with a period not equal to 24 hours. To remain in phase with the 24-hour daily cycle of the environment, a circadian rhythm must be phase-shifted every day. Phase-shifting cues, such as the onset of light and dark, entrain circadian rhythms to the natural 24-hour period. Review Figure 52.13 See Web/CD Tutorial 52.2 In mammals, the clock that controls the circadian rhythm is located in the suprachiasmatic nuclei of the brain. In other animals, different structures function as the circadian clock. Review Figure 52.14 Genes with self-regulating feedback loops of transcription and translation have been identified as the

cellular clock mechanism in a variety of species. Review Figure 52.15 Circannual rhythms ensure that animals, such as hibernators and equatorial migrants, that cannot rely on changes in day length as seasonal cues perform the appropriate behaviors at the appropriate times of year. Finding Their Way: Orientation and Navigation Piloting animals find their way by orienting to landmarks. Animals that navigate by distance and direction determine distance in part by recognizing landmarks in the vicinity of their destination and in part by biological rhythms that determine how far they travel. Review Figure 52.17 Sources of directional information include a time-compensated solar compass and an ability to locate a fixed point in the night sky. Review Figure 52.18 See Web/CD Tutorial 52.3 Human Behavior Human behavior, like that of all other animals, consists of genetically determined and learned components. What distinguishes humans is the extent to which we can modify our behavior on the basis of experience and pass those modifications on to others.

CHAPTER 53: BEHAVIOR ECOLOGY Behavioral ecology is the study of how animals decide where to carry out different activities, select the resources they need, respond to predators and competitors, and interact with other members of their own species. An organism's environment includes both abiotic and biotic components. Responding to Environmental Variation Organisms respond adaptively to environmental changes. The cues animals use to select habitats may be simple, but they must be good predictors of conditions suitable for future survival and reproduction. The success of already settled individuals may provide evidence of habitat quality. Review Figure 53.3 Cost-benefit analyses of behavior are based on the principle that animals have only limited amounts of time and energy to devote to their activities. Behaviors such as defending a territory may have three kinds of costs: energetic cost, opportunity cost, and risk cost. Review Figure 53.4. See Web/CD Tutorial 53.1 Foraging theory was developed to understand how animals select foods from those present in the environment. Review Figure 53.5. See Web/CD Tutorial 53.2 The human taste for spices may have evolved because spices have antimicrobial activity. Review Figure 53.7 Because males produce enough sperm to fertilize many more eggs than a single female can produce, males typically increase their reproductive success by mating with many females. The reproductive success of females, on the other hand, is typically limited by the cost of producing eggs. As a result, males usually initiate courtship and often fight for opportunities to mate with females. Females seldom fight over males and often reject courting males. Courting males perform behaviors that signal their desirability as mating partners. By paying particular attention to those signals at which males cannot cheat, females have favored the evolution of "reliable" signals. The Evolution of Animal Societies Social systems are best understood not by asking how they benefit the species as a whole, but by asking how the individuals that join together benefit by the association. Social systems are dynamic; individuals constantly communicate with one another and adjust their relationships. Living in a group may provide protection against predators. Review Figure 53.10 The origin of most animal societies is the family, an association of one or more adults and their

dependent offspring. Altruism among closely related individuals can evolve by means of kin selection because individuals who help close relatives can improve their inclusive fitness. Review Figure 53.11 Eusocial systems with sterile individuals have evolved among hymenopterans (ants, bees, and wasps), termites, and one mammal, the naked mole-rat. The more closely related the individuals in a colony are to one another, and the greater the difficulty of establishing independent colonies, the more likely eusociality is to evolve. Behavioral Ecology, Population Dynamics, and Community Structure Social animals may achieve great abundances. Interspecific interactions, as well as habitat and food choices, influence animal distributions. See Web/CD Activity 53.1 for a concept review of this chapter. CHAPTER 54: POPULATION ECOLOGY Populations in Space and Time A population consists of all the individuals of a species within a given area. The number of individuals of a species per unit of area (or volume) is its population density. Dense populations often exert strong influences on populations of other species. Life tables summarize information about births and deaths in populations. Review Table 54.1 Graphs of survivorship in relation to age show when individuals survive well and when they do not. Review Figure 54.1 The age distribution of individuals in a population reveals much about the recent history of births and deaths in the population. The timing of births and deaths may influence age distributions for many years. Review Figure 54.2 Types of Ecological Interactions Individuals of two populations may interact in ways that may benefit or harm either or both participants. Review Table 54.2. See Web/CD Activity 54.1 Factors Influencing Population Densities Species with small individuals typically achieve higher population densities than species with large individuals. Review Figure 54.4 Introduced species sometimes achieve great population densities. Review Figure 54.5 Fluctuations in Population Densities All populations have the potential to grow exponentially under optimal conditions. Review Figure 54.6. See Web/CD Tutorial 54.1 No population can maintain exponential growth for very long because environmental limits cause birth rates to drop and death rates to rise. The number of individuals of a particular species that an environment can support—called the carrying capacity (K)—is determined by the availability of resources and by disease and predators. A population in a limited environment shows a logistic growth pattern, in which growth rates decrease as the carrying capacity is approached. Review Figure 54.7. See Web/CD Activity 54.2 and Tutorial 54.2 The density of a population is influenced by the combined effects of all density-dependent and density-independent factors affecting it. Review Figure 54.8 Population Fluctuations Populations do not fluctuate as much as theoretically possible, but some fluctuate much more than others. The amount of fluctuation is influenced by body size, reproductive rate, and range size. Review Figure 54.9 Population fluctuations may be strongly influenced by years of good reproduction. Review Figure 54.10 Predator-prey interactions may generate population cycles. Review Figures 54.11, 54.12 Populations of many species exist as small, fragmented subpopulations. Extinction of subpopulations is common, but individuals from other fragments may recolonize them. Review Figures 54.13, 54.14. See Web/CD Tutorials 54.3 and 54.4 Variation in Species' Ranges Some species are restricted to very small areas, whereas others are widely distributed on Earth. Species' ranges are influenced by speciation processes, dispersal abilities, predators, and competition. Review

Figures 54.16, 54.17 Managing Populations Humans can use the principles of population dynamics to control and manage populations of desirable and undesirable species. Nevertheless, humans have overexploited many populations. Review Figure 54.18 Regional and Global Processes Influence Local Population Dynamics Population densities may be influenced by both local conditions and remote events. Review Figure 54.20 CHAPTER 55: COMMUNITIES AND ECOSYSTEMS Ecological communities are assemblages of species, each of which interacts in unique ways with its environment. In most cases, species drop out of and are added to communities gradually across environmental gradients. Review Figure 55.1 Communities: Loose Assemblages of Species Experiments can tell us which interactions among species exert the strongest effects on community structure. Review Figure 55.2 Process and Pattern in Communities and Ecosystems Most of the energy incorporated by an organism is used in its respiration. Only a small proportion can be captured by other organisms that consume it. Review Figure 55.3 See Web/CD Activity 55.1 Primary production is determined by temperature and precipitation. Therefore, it varies over Earth's surface. Review Figures 55.4, 55.5 Species richness increases with primary production up to a point, after which it declines. Review Figure 55.6 A trophic level consists of those organisms whose major food source has passed through the same number of steps. See Web/CD Activity 55.2 Food webs are diagrams of who eats whom in ecological communities. Most food webs have only three to five trophic levels. Review Figure 55.7 Energy pyramids show the flow of energy through trophic levels. Biomass pyramids show the amount of living matter at each trophic level. Review Figure 55.8 Communities with more species are generally more productive and more stable than communities with fewer species. Review Figure 55.9 Keystone species influence community structure and dynamics out of proportion to their abundances. Review Figure 55.10 Disturbance and Community Structure All ecological communities are subjected to a variety of disturbances. Typically, small disturbances are much more common than large ones. Communities subjected to moderate levels of disturbance typically have more species than communities subjected to lower or higher levels of disturbance. Review Figure 55.13 After a disturbance, the structure and composition of an ecological community changes as organisms modify the physical environment and interact with one another. Review Figures 55.14, 55.15 See Web/CD Tutorial 55.1 Dispersal, Extinction, and Community Structure The composition of ecological communities is influenced by ecological and evolutionary events taking place over long time periods and large spatial scales. CHAPTER 56: BIOGEOGRAPHY Biogeography is the science that attempts to describe and explain patterns in the distribution of life on Earth. Earth's Biogeographic Regions If a species occupies a particular area, either it evolved there, or it evolved elsewhere and dispersed to that area. If a species is not found in a particular area, either it evolved elsewhere and never dispersed to that area, or it was once present in that area but no longer lives there. Biogeographers divide Earth into several major biogeographic regions. Review Figure 56.1 Remote islands contain many endemic species. History and Biogeography Continental drift has influenced the distributions of organisms throughout Earth's history. Biogeographers often analyze species distributions by converting phylogenies into area phylogenies. Review Figure 56.3 See Web/CD Activity 56.1 Distribution patterns can result from vicariant events or from dispersal. The principle of parsimony is used to explain distribution patterns. Review Figure 56.4

Ecology and Biogeography Global atmospheric circulation is driven by solar energy input. Review Figure 56.6 See Web/CD Tutorial 56.1 Wind circulation patterns influence the amount and seasonal nature of rainfall. Review Figures 56.5, 56.7 Global oceanic circulation is driven by winds. Review Figure 56.8 Terrestrial Biomes Terrestrial biomes are major ecosystem types that differ from one another in the structure of their dominant vegetation. The distribution of biomes on Earth is strongly influenced by annual patterns of temperature and rainfall. Review Figure 56.9 The major terrestrial biomes are tundra, boreal forest, temperate deciduous forest, temperate grassland, cold desert, hot desert, chaparral, thorn forest and savanna, tropical deciduous forest, and tropical evergreen forest. Review Pages 1076-1085. See Web/CD Tutorial 56.2 Aquatic Biogeography Only about 2.5 percent of Earth's water is found in ponds, lakes, rivers and streams, but about 10 percent of all aquatic species live in freshwater habitats. Even though no absolute barriers to the movement of marine organisms exist within the oceans, most marine organisms have restricted ranges. The boundaries between oceanic biogeographic regions are determined by ocean currents and changes in water temperature and salinity. Review Figure 56.10 Species that live in shallow waters disperse with difficulty across wide deep-water barriers. Review Figure 56.11 Regional Patterns of Species Richness Species richness increases rapidly when the area being sampled crosses a biogeographic boundary. Review Figure 56.12 The number of species in most lineages increases from polar to tropical regions. Review Figure 56.13 MacArthur and Wilson's model of species richness, which predicts the number of species on islands, has been tested by examining patterns of distribution. Review Figures 56.14, 56.15, Table 56.1 See Web/CD Tutorial 56.3 Biogeography and Human History The distributions of plants, animals, and continents have exerted powerful influences on human history. CHAPTER 57: CONSERVATION BIOLOGY Humans have caused extinctions of species for thousands of years, but the rate of human-caused extinctions is rising rapidly today. Why Care about Species Extinctions? Species provide the food, fiber, medicines, and aesthetic opportunities upon which the quality of human life depends. The extinction of species as a result of human activities raises serious ethical issues. Extinctions deprive us of opportunities to understand ecological relationships among organisms. Ecosystems provide valuable services that can be replaced only by expensive and continuing human effort. Review Figure 57.1 Estimating Current Rates of Extinction Estimates of current rates of extinction are based primarily on species-area relationships and population models. Preserving Biodiversity Habitat destruction is the most important cause of species extinction today. Review Figure 57.2 A greater proportion of small than large habitat patches is affected by external influences. Review Figures 57.3, 57.4 Invasive species are major causes of extinction. Biologists use information on species that have become invasive to identify species likely to become invasive if introduced. Review Figure 57.5 Certification programs enable consumers to purchase materials produced in ways that do not harm biodiversity. Overexploitation, which historically resulted in most human-caused extinctions, is still an important cause of extinctions today. Information on how species are affected by disturbances helps conservation biologists decide where to reestablish historic disturbance patterns. Species have responded at different rates to past climate changes. Review Figure 57.7 Habitat Restoration and Species Recovery

Restoration of habitats is often necessary to preserve species. Restoration of some ecosystem types, especially wetlands, is difficult. Review Figure 57.9 Captive propagation plays a useful but limited role in conservation. Healing Biotas: Conservation Medicine Disease outbreaks among wild species are increasing. Some of these diseases can be transmitted to humans. The new field of conservation medicine is helping to identify the causes of increases in diseases and to devise effective solutions. See Web/CD Activity 57.1 for a concept review of this chapter. CHAPTER 58: EARTH SYSTEM SCIENCE Earth's System Has Four Compartments The elements on which life depends cycle among the four compartments of Earth's physical environment: oceans, fresh waters, atmosphere, and land. Review Figure 58.1 Primary production in oceans is highest in zones of upwelling adjacent to continents, where nutrient-rich waters rise to the surface. Review Figure 58.2 Water moves rapidly through lakes and rivers. Gases in the atmosphere are important regulators of temperatures on Earth. Regional and local deficiencies of particular elements strongly affect ecosystem processes on land. Biogeochemical Cycles, Water, and Fire The hydrological cycle is driven by evaporation of water, most of it from ocean surfaces. Review Figure 58.4 See Web/CD Tutorial 58.1 Human activities have altered the flux of water from the land to the oceans. Review Figure 58.5 Biomass burning contributes great quantities of carbon to the atmosphere. The Carbon Cycle Atmospheric carbon dioxide is the immediate source of carbon for terrestrial organisms, but only a small part of Earth's carbon is in the atmosphere. Review Figure 58.6 See Web/CD Tutorial 58.2 Increasing concentrations of carbon dioxide in the atmosphere are changing climates and influencing ecological processes. Review Figure 58.7 The ocean conveyor belt carries great quantities of carbon to the deep ocean. See Web/CD Tutorial 58.3 The Nitrogen Cycle Nitrogen makes up 78 percent of Earth's atmosphere, but nitrogen can be converted into biologically useful forms only by a few species of microorganisms. Review Figure 58.9 See Web/CD Tutorial 58.4 Runoff of nitrogen from agricultural lands causes eutrophication in aquatic ecosystems. Review Figure 58.10 The Sulfur Cycle Acid precipitation results from the combined effects of human alterations in the nitrogen and sulfur cycles. Review Figures 58.11, 58.12 The Phosphorus Cycle The phosphorus cycle differs from the cycles of carbon, nitrogen, and sulfur in that it lacks a gaseous phase. Review Figure 58.13 As a result of high fertilization rates, great quantities of phosphorus are accumulating in agricultural soils. Review Figure 58.14 Eutrophication resulting from human inputs of phosphorus has damaged ecosystems in many lakes. Interactions among Biogeochemical Cycles Human alterations of global biogeochemical cycles are changing Earth's climate. Outbreaks of diseases are one effect of this global warming. Visions of the Future Actions people might undertake today could greatly influence the future quality of human life and the welfare of other species that share our small planet with us.